1961

# Air resistance of perforated grain bin floors

William Phillip Lampman
*Iowa State University*

# AIR RESISTANCE OF PERFORATED GRAIN BIN FLOORS

by

William Phillip Lampman

A Thesis Submitted to the

Graduate Faculty in Partial Fulfillment of

The Requirements for the Degree of

MASTER OF SCIENCE

Major Subject: Agricultural Engineering

Signatures have been redacted for privacy

Iowa State University
Of Science and Technology
Ames, Iowa

1961

1176-9 e

TABLE OF CONTENTS


| | |
|---|---|
| DEFINITION OF SYMBOLS | 1 |
| INTRODUCTION | 3 |
| OBJECTIVES | 6 |
| LITERATURE REVIEW | 7 |
| ANALYSIS OF THE PROBLEM | 13 |
| EXPERIMENTAL APPARATUS | 19 |
| EXPERIMENTAL PROCEDURE | 32 |
| RESULTS AND DISCUSSION | 41 |
| APPLICATION OF RESULTS | 78 |
| SUMMARY AND CONCLUSIONS | 84 |
| SUGGESTED FUTURE STUDIES | 87 |
| BIBLIOGRAPHY | 88 |
| ACKNOWLEDGMENTS | 90 |
| APPENDIX A: ORIGINAL AND CALCULATED DATA FOR TESTS 1 THROUGH 11 | 91 |
| APPENDIX B: DATA AND CALCULATIONS FOR CALIBRATING THE AIR DISPLACEMENT PUMP AND THIN PLATE ORIFICES | 133 |
| APPENDIX C: ORIGINAL AND CALCULATED DATA FOR AUXILIARY TESTS | 138 |

## DEFINITION OF SYMBOLS

The definition of symbols given in Table 1 will be used throughout this manuscript.

Table 1. Definition of symbols

| Symbol | Description | Units |
|---|---|---|
| A | Area | $ft^2$ |
| C | Coefficient used in predicting Euler number | --- |
| C' | Coefficient used in predicting $\Delta P$ | --- |
| $C_d$ | Coefficient of discharge | --- |
| D | Hydraulic diameter of duct | ft |
| d | Diameter of perforation | in. |
| F | Ratio of open area to total area of perforated sheet | --- |
| F' | Percent open area | --- |
| f | Function | --- |
| G | Grain influence factor | --- |
| g | Acceleration of gravity | $ft/sec^2$ |
| H | Equivalent depth of grain | ft |
| h | Static pressure head | in. of water |
| K | Constant applied to velocity head change | --- |
| L | Static pressure head | ft |
| P | Center to center distance between perforations | in. |
| Q | Air flow rate | cfm |
| R | Reynolds number | --- |

Table 1. (Continued)

| Symbol | Description | Units |
|---|---|---|
| $t$ | Thickness of perforated sheets | in. |
| $V$ | Velocity | ft/sec |
| $V'$ | Velocity | ft/min |
| $w$ | Specific weight of air | $lb/ft^3$ |
| $x$ | Distance from the dead end of duct | ft |
| $\Delta P$ | Apparent static pressure drop across the perforated sheet | $lb/ft^2$ |
| $\beta$ | Ratio of orifice diameter to pipe diameter | --- |
| $\delta$ | Friction factor (16) | --- |
| $\mu$ | Absolute viscosity of air | $lb\ sec/ft^2$ |
| $\rho$ | Density of air | $slugs/ft^3$ |

The following subscripts were used.

a Apparent

d Duct

f Open

o Dead end of duct

p Pressure

s Suction

t Total

## INTRODUCTION

Ventilation or aeration is a useful method of preserving the market quality of stored grain. In recent years increasing interest in the design of ventilating systems has developed as a result of the large accumulation of surplus grain stored both "on the farm" and in private and Federal Government owned storage depots. The practice, common among grain warehousemen, to periodically "turn" grain to help maintain quality is an expensive operation where large flat-bottomed storages are in use. Mechanical ventilation, while applicable to all types of storage, has a particular advantage in large flat storages where it is difficult to move or "turn" the grain.

The use of ventilating systems is not new. Holman (6) states that a patent was granted in 1935 for an aeration and fumigation system. Holman (6) further comments that while several of these units were installed in elevators, they did not prove satisfactory. Their failure was attributed either to design, which was not in accordance with engineering principles, or operation outside the design limits.

Holman (6) cites the following purposes of ventilating systems in grain storages:

1. Cooling grain to prevent or minimize mold growth and insect activity.
2. Equalizing temperatures in stored grain to prevent moisture from moving from warm to cool grain.
3. Removing odors from stored grain.

4. Applying fumigants to stored grain.

5. Holding moist grain in storage for brief periods of time.

These purposes may be achieved with relatively small amounts of air. Holman (6) states that the commonly used rates vary from 1/20 to 1/10 cfm per bushel. Foster and Stahl (3) indicate that air flow rates of 1/50 to 1/100 cfm per bushel are effective in preventing accumulation of surface moisture in corn which was stored at a moisture content of 12 percent. Robinson et al (12) has stated that effective cooling has been obtained in Iowa tests using 1/10 cfm per bushel and that lower rates probably would be satisfactory if a longer cooling period can be tolerated.

These citations emphasize the fact that satisfactory ventilation may be achieved with small amounts of air, provided this air can be distributed throughout the mass of grain. In deep storages or small bins uniform distribution can be achieved using false floors. Although perforated false floors provide a theoretically perfect air distribution duct, they are relatively high in cost. Other less costly systems permitting some non-uniformity of air flow may be satisfactorily substituted for a false floor.

In large flat storages false floors are uneconomical and air must be distributed with a duct system. Shove (16) indicates that the design of a uniform cross section ventilating duct may be reduced to two phases: (a) prediction of the static pressure gradient along the length of the duct, and (b) selection of the free or open area to produce uniform air intake or discharge along the length of the duct. Shove (16) has provided a satisfactory solution to the problem of predicting the static pressure gradient along the duct. The purpose of the following study was to supply information relative to the second phase of the general problem of designing a satisfactory ventilating duct.

## OBJECTIVES

Specifically this study was undertaken to establish the relationship among the variables influencing the apparent static pressure drop through a specific type of perforated sheet metal when supporting particular grains.

## LITERATURE REVIEW

Shove (16) developed an equation for the prediction of static pressure in a perforated duct. This equation has the form:

$$dL/dx = -K\ d/dx\ (V^2/2g) \pm \delta\ V^2/D2g \qquad (1)$$

This expression indicates that the rate of change of static pressure equals a constant K, times the rate of change of velocity head plus or minus the rate of change of friction head. The constant K was evaluated experimentally as

K = 1.50 for dividing flow (pressure system)

K = 1.70 for combining flow (suction system)

If the assumption is made that the quantity of air per unit area passing through the duct wall is uniform throughout the length of the duct, Shove (16) has shown that the solution to the differential equation may be put in the following form:

$$h - h_o = (V'_d/4000)^2\ (-1.7 - \delta x/3D)\ \text{combining flow} \qquad (2)$$

$$h - h_o = (V'_d/4000)^2\ (-1.5 + \delta x/3D)\ \text{dividing flow} \qquad (3)$$

There appears to be two solutions to the problem of providing uniform air flow through the walls of a constant cross-section duct. The duct size may be increased thus reducing both friction and the velocity head to small quantities, or the ventilating air may be throttled as it passes through the duct wall. To minimize the pressure gradient along the duct and thus reduce unequal air distribution, Holman

(6) proposes that the maximum air velocity within the duct be limited to the following values.

| Duct length ft | Air velocity within the duct fpm |
|---|---|
| 5 - 25 | 2000 |
| 25 - 60 | 1500 |
| 60 - 100 | 1000 |

Holman (6) also notes that under certain conditions, particularly for short ducts, the surface area may be the limiting factor in determining duct cross-sectional area. For upright storages the suggested duct surface velocity is 30 to 50 fpm; for flat storages duct surface velocities should be limited to 20 to 30 fpm. Although no specific test information was published, it is assumed that the use of Holman's design data would result in the design of a duct which would provide satisfactory air distribution; however, duct size may become relatively large and consequently expensive. Ringle (11) describes the very unsatisfactory air distribution pattern resulting from the use of a duct having a cross-sectional area of 1.5 sq ft in a 120-foot-long building. Ringle (11) further outlines how the use of a paper air meter, to throttle air through the duct wall, greatly improved the distribution pattern.

The design of a section of perforated sheet metal to support a porous media, such as grain, should meet several basic requirements. It should be structurally strong, should prevent excessive passage of material through the sheet and should provide control of the resistance to the flow of air through it. These requirements complicate the matter of selecting a perforated sheet. Adequate strength necessitates a minimum sheet thickness. Holman (6) suggests a minimum of 14 to 16 gauge for circular perforated and corrugated steel aeration ducts in upright storages and 16 to 20 gauge for flat storages. This recommendation appears to be based on existing practice in commercial installations. The open area will also influence the strength of the perforated material. For maximum strength the minimum free area consistent with the desired flow characteristic should be selected. Holman (6) suggests that the perforated area should equal 10 percent of the total surface. The U. S. Department of Agriculture Leaflet No. 332 (19) quotes a minimum of 7 percent open area for perforated false floors. To minimize the loss of grain through a perforated section of material, consideration must be given to the size of the perforations. Holman (6) states that a hole 3/32 in. in diameter or a slot 5/64 in. wide will not allow normal sized kernels of wheat to pass.

The resistance to the passage of air created by a perforated material is dependent upon the type of perforations and the solidity ratio or percentage open area. In certain installations such as for batch dryer walls and for duct work for deep storages, it is of interest to know the minimum open area which will cause negligible pressure drop across the sheet. In the design of optimum ventilating systems for flat storages, it is necessary to have a knowledge of the resistance created by the duct wall and supported grain. First, considering the resistance created by uncovered perforated sheets Kolodize and Van Winkle (9) made a study using perforated plates having round holes on an equilateral triangle pitch. These plates were mounted in a flange mounting between two sections of 3-in. I.D. Pyrex pipe. The discharge coefficient for the perforated plate was correlated with Reynolds number, pitch to hole diameter and plate thickness to hole diameter. In this study, Reynolds numbers ranged from 2,000 to 20,000. Later, a similar study covering the range of Reynolds numbers from 400 to 3,000 was made by Smith and Van Winkle (17). In the above studies a semi-empirical approach was used. The factors considered to affect the orifice coefficient for perforated plates were:

1. Fluid velocity through the orifice.
2. Fluid density.
3. Fluid viscosity.
4. Hole diameter.
5. Hole pitch.
6. Thickness of the plate.

Considering these variables, Kolodize and Van Winkle (9) wrote the following dimensionless equation:

$$C_d = f\left(\rho V d/\mu,\ d/P,\ t/d\right) \tag{4}$$

This equation was used as a basis for the correlation of the experimental data. Assuming that the maximum area of the plate was perforated, the coefficient of discharge for the orifice plate was calculated by means of the following relationship:

$$V = C_d \sqrt{\frac{2g(-\Delta P)}{w\left[1-(F)^2\right]}} \tag{5}$$

Smith and Van Winkle (17) constructed plots of the coefficient of discharge versus the thickness to diameter ratio for a series of Reynolds numbers ranging from 400 to 3,000. Examination of these plots in the range of thickness to diameter ratio below one shows that the coefficient of discharge increases with an increase in the thickness to diameter ratio.

Henderson (4, 5) reports on the pressure drop through two types of perforated sheet metal supporting grain. One type of perforation used consisted of a rectangular-shaped punched opening; while the other was prepared by an indentation process.

Henderson's data are presented in graphical form along with the following mathematical expressions which were developed to fit the experimental data.

| | |
|---|---|
| Bin wall without grain | $H(F')^{1.59} = 2.97$ |
| Bin wall with corn | $H(F')^{1.55} = 7.40$ |
| Bin wall with soybeans | $H(F')^{1.27} = 7.30$ |
| Bin wall with oats | $H(F')^{1.62} = 5.25$ |

In explaining the cause of the increased resistance attributed to the grain, Henderson (4) made the following comment:

> The added resistance with corn was evidently due to the reduction of the effective opening by the kernels. The reduction was the greatest in the sheets with large rectangular-shaped perforations.

Henderson (4) further states,

> A large number of small perforations is to be preferred over a smaller number of larger perforations for the same amount of opening.

An explanation of the latter statement was not included in the discussion.

## ANALYSIS OF THE PROBLEM

The problem of predicting the pressure drop across a perforated sheet supporting a porous media, for example, grain, cannot be confined to a study of the sheet alone. The pressure gradient in the media in proximity with the sheet plus the influence of the media in reducing the effective area of the perforations must be considered. The number and nature of the variables involved make a rigorous theoretical analysis almost impossible. In this study an empirical approach was used.

The pressure drop through a perforated sheet supporting a porous media depends upon the geometry of the sheet, the fluid, the media and the flow. The perforated sheets used in this study had round holes punched on an equilaterial triangle pitch (Figures 1 and 2).

The variables considered pertinent to the problem together with their basic dimensions are:

| | | |
|---|---|---|
| $V$ | fluid velocity | $LT^{-1}$ |
| $d$ | hole diameter | $L$ |
| $P$ | hole pitch | $L$ |
| $t$ | sheet thickness | $L$ |
| $\rho$ | fluid density | $FT^2L^{-4}$ |
| $\mu$ | absolute viscosity of the fluid | $FTL^{-2}$ |
| $G$ | grain influence factor | (-) |
| $\Delta P$ | apparent pressure drop across the perforated sheet | $FL^{-2}$ |

These variables may be related by the following expression:

$$\Delta P = f(V, d, F, t, \rho, \mu, G) \quad (6)$$

Since three independent dimensions are involved, the Buckingham Pi theorem indicates that a relationship could be developed using five dimensionless groups or Pi terms (10). These were written as:

$$\Delta P/\rho V^2 = f(\rho Vd/\mu, P/d, t/d, G) \quad (7)$$

Based on the geometry of the sheet and the assumption that the sheet is large in comparison with the hole pitch, F may be evaluated in terms of the hole pitch to diameter ratio.

Considering a single hexagon in Figure 2,

$$A_f = \pi d^2/4$$

$$A_t = 0.866\ P^2$$

$$F = A_f/A_t = 0.907\ (d/P)^2 \quad (8)$$

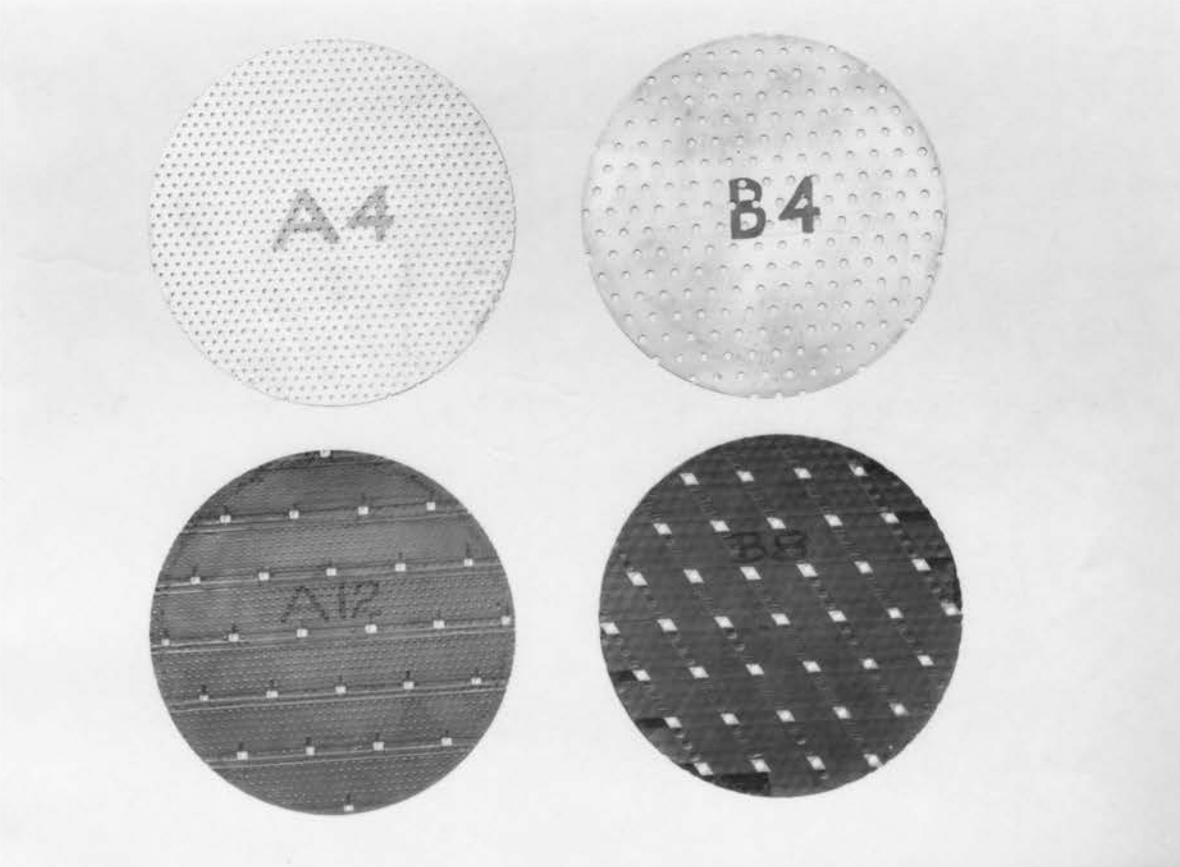
Application of the principles of dimensional analysis (10) and noting that $\rho Vd/12\mu$ is Reynolds number and $F = f(P/d)$, Equation 7 may be written

$$\Delta P/\rho V_a^{\ 2} = f(R, F, t/d, G) \quad (9)$$

The factor 12 was introduced into the denominator of the expression for Reynolds number to convert the diameter of the hole expressed in in. to ft.

The dimensionless term G expresses the characteristics of the grain. Included are such factors as shape, moisture content, amount of foreign material, mechanical damage and porosity. For a particular combination of grain and hole diameter, G is assumed constant; however, changing the

Figure 1. Examples of the type of perforated sheets used in Tests 1 to 11 inclusive


A4
B4
A12
B8

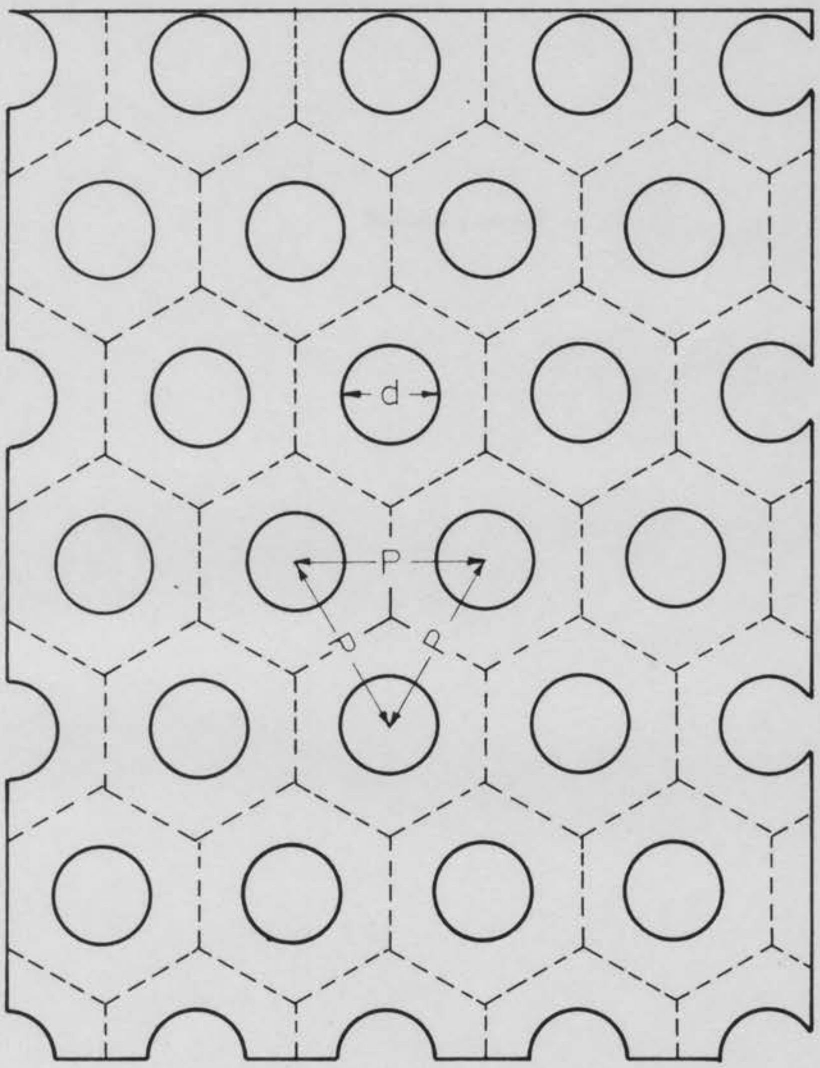



Figure 2. Perforated sheet having holes punched on an equilateral triangle pitch

character of the grain or hole diameter may result in a new value of G. In calculating the value of the Pi term $\Delta P/\rho V_a^2$, known as the Euler number, the apparent velocity was selected in preference to the average velocity through the perforations. This selection separates the curves of Euler number versus Reynolds number for the various values of F. Separation of the curves facilitates analysis.

Other factors such as pressure tap location and shape of the upstream orifice edges were assumed to be constant in this investigation. Equation 9 was used as a basis for correlating the experimental data.

## EXPERIMENTAL APPARATUS

The experimental equipment (Figures 3 and 4) consisted of an air pump, turbine, thin plate orifice meter, plenum chamber, manometers and a section of grain bin. The air pump was essentially the same as that described by Shedd (15). This equipment was modified to eliminate the jack shaft and the necessity of changing sprockets and chain to vary the rate of displacement of the bell. Two automotive type transmissions were installed in the drive system which greatly facilitated changing the pump displacement rate. Bunn (2) has described the gear train and tabulated the air flow rates for the various combinations of gears and sprockets used with this apparatus.

The turbine was a Spencer turbo compressor manufactured by the Spencer Turbine Company of Hartford, Connecticut. The manufacturer specifies that it is capable of delivering 125 cfm at a static pressure of 1 inch of mercury. The turbine was equipped with a 1½ hp, 7200 rpm universal electric motor. The original plan was to control the speed of the turbine and thus the air flow with a 20-ampere General Radio variac; however, experience showed that more accurate control could be achieved by a combination of the variac and an air bleed at the turbine inlet. The turbine and air pump were connected to the plenum chamber by two sections of thin wall steel tubing. Suitable flanges were threaded on the tubing to facilitate construction of a thin plate orifice meter as described in the A.S.M.E. Power Test Code (1). A set of three orifice plates were machined and surface ground to permit measurement of air flow using the published values of flow coefficient (1).

Figure 3. Grain column and plenum chamber with auxiliary equipment for metering and supplying air

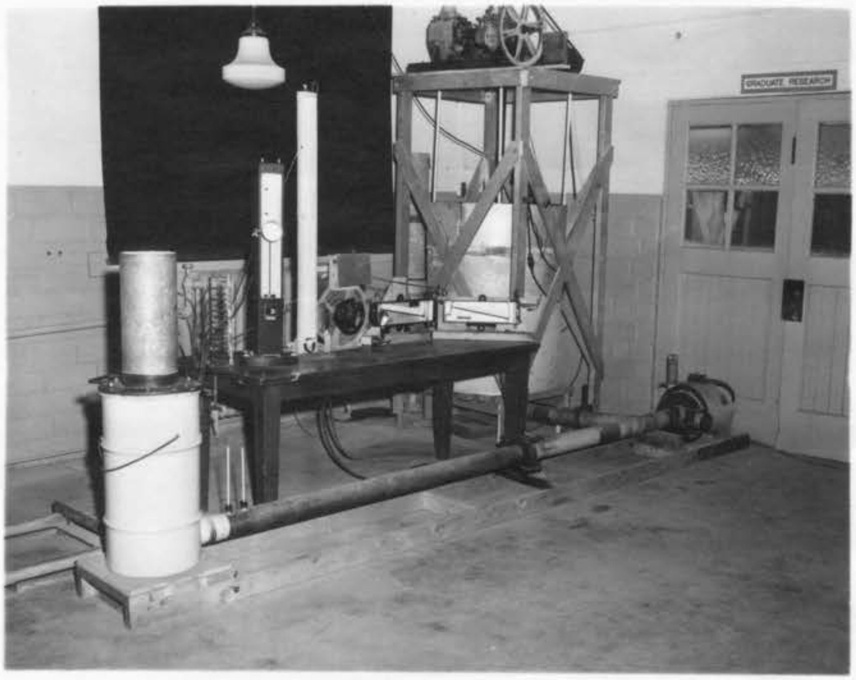
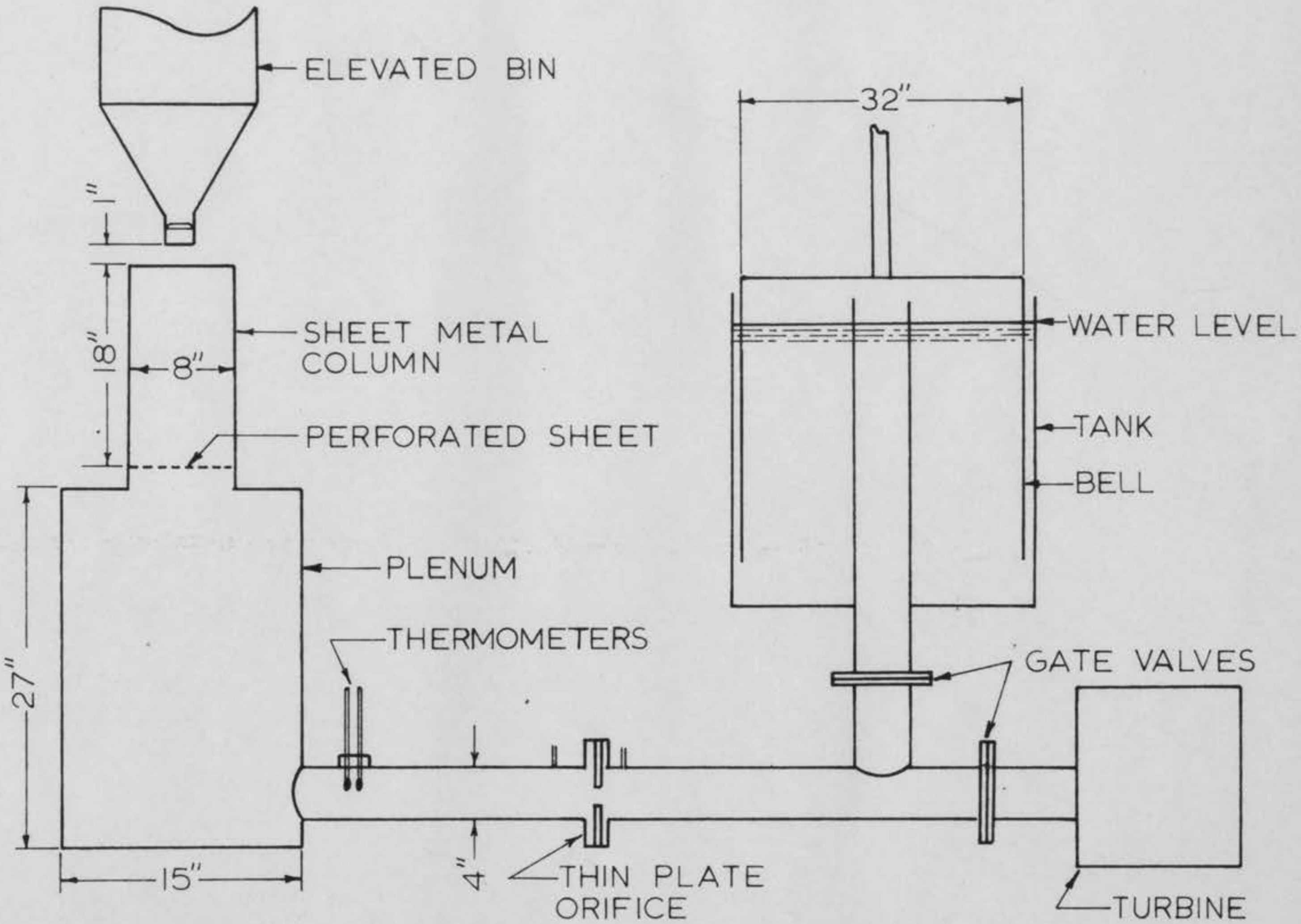

GRADUATE RESEARCH

Figure 4. Apparatus for supplying and metering air at constant known rates


ELEVATED BIN
1"
18"
8"
SHEET METAL
COLUMN
PERFORATED SHEET
PLENUM
27"
15"
THERMOMETERS
4"
THIN PLATE
ORIFICE
32"
WATER LEVEL
TANK
BELL
GATE VALVES
TURBINE

As the average inside diameter of the pipe was 3.852 in., it was necessary to interpolate between the values published in the A.S.M.E. Power Test Code (1) for the flow coefficients for a 3-in. and 4-in. diameter pipe and construct a graph of Reynolds number versus flow coefficients for each orifice plate. The test code permits this practice. Table 2 lists the orifice diameter and value of β for the three orifice plates.

Table 2. β, ratio of orifice diameter to inside pipe diameter

| β | Orifice diameter (in.) |
|---|---|
| 0.200 | 0.770 |
| 0.250 | 0.9625 |
| 0.350 | 1.347 |

The calibration of the two smaller orifice plates was checked using the air displacement pump. The values of the rate of air displacement calculated from the pump dimensions and speed, and the orifice meter were compared. The 1.347-in. diameter orifice calibration was compared with a 1 1/4-in. Rothern Engineering Company fiberglass flow nozzle. The maximum percentage difference between the observed flow rates through the orifice plates and the displacement pump was 3.6 percent. The percentage difference was based on the flow rate of the displacement pump. A similar comparison between the 1.347-in. orifice plate and the 1 1/4-in. flow nozzle yielded a maximum difference of 3.4 percent based on the flow rate through the nozzle. Complete data for this series of tests is shown in Appendix B. Based on the above results, it was concluded that the use of the orifice plates and flow coefficients obtained from the A.S.M.E. Power Test Code (1) would provide a reasonably accurate air metering device for use with the Spencer turbine.

The cylindrical plenum chamber was 27 in. high and 15 in. in diameter. A 1/4-in. circular steel plate with a 10-in. diameter opening was welded to the top of the plenum chamber. This plate had six 1/2-in. N.F. bolts threaded into holes equally spaced around a 12 5/16-in. diameter circle.

A suitable cover plate was also fabricated. This cover was constructed with a centrally located collar so that a perforated disc and the sheet metal column could be assembled and removed. A seal between the collar and metal column was obtained using two layers of 1-in.-wide masking tape covered with a 2-in.-wide rubber band. To bolt the cover plate to the plenum chamber, holes were drilled in the cover plate which aligned with the bolts in the steel plate welded to the plenum chamber. An airtight seal between the two plates was obtained by cementing a sheet of 1/4-in. rubber gasket material to each of the plates.

Pressure measurements were made at the plenum chamber and at the 1-, 3-, 5-, 9- and 12-in. points above the perforated sheets. Pressure measurements at the plenum chamber were made with a piezometer ring formed by wrapping a length of 1/4-in. copper tubing around the plenum chamber and connecting it to the chamber with five small holes. Pressure measurements on the column were made from taps which consisted of short lengths of 1/4-in. copper tubing connected to the column by two 1/16-in. holes spaced 1/8 in. apart.

A study of work by a number of investigators (8), (13), (14) shows that the resistance offered to the flow of fluid through a bed of granular material is not independent of the size of the container into which the material is placed. Rose (13) concluded that the effect of the container wall for a circular column may be neglected when the ratio of column diameter to particle diameter is greater than 50. For an 8-in. diameter column the maximum effective particle diameter would be 0.16 in. While no value for the effective diameter of grain kernels is published, corn probably slightly exceeds the above ratio. Shedd (15), however, conducted a series of tests with corn in an 8-in. diameter tube. He concluded that the effect of the container was small. Kelly (8) carried out tests using a 1 ft. 6 in.-diameter column and concluded that the walls had no effect on the flow of air through the column. Based on this work, the assumption was made that the effect of the walls of the 8-in. diameter sheet metal column on the pressure gradient through the column of grain would be sufficiently small that it could be neglected.

A quantity of perforated sheet metal was obtained from the Harrington and King Perforating Co., Inc., Chicago, Illinois. An 8-in. centerless hole saw (Figure 5) was constructed to facilitate cutting a series of 8-in. diameter discs from the perforated material. Certain of these discs were then taped using a pressure sensitive tape so as to provide a series of sheets, the open area of which approximately doubles

Figure 5. Hole saw constructed to cut 8-in. diameter discs from the perforated steel stock

from disc to disc. The various discs are described in Table 3. In the process of the experiment some of the perforated discs having the larger open area were not used, the reason being that the pressure drop across these sheets was too low to be accurately measured with the available manometers.

Two values of the open area of the discs are listed in Table 3. The calculated value was obtained using Equation 8. This value would apply for a large sheet. The observed value was obtained by counting the actual number of holes which were exposed after the sheet was mounted in the cover plate and sealed with wax. Partial holes in the periphery of sheets A14, B11, B12 and B13 were not sealed. The amount of hole exposed was estimated after the sheet was mounted. The purpose of leaving these partial holes exposed was to maintain the actual open area approximately equal to the calculated values. The observed value was used in all calculations involving the open area of the sheets.

To investigate the influence of the ratio of sheet thickness to hole diameter on the Euler number, three 8-in.-diameter discs were prepared from 20-gage, 14-gage and 1/8-in. steel material. Ninety-six 3/16-in.-diameter holes were drilled in each disc in a staggered pattern on a 0.75-in. pitch. No holes were drilled in the periphery of these discs. The thickness to hole diameter ratio for the three discs was 0.189, 0.384 and 0.674, and the open area was 5.27 percent. The sheets were designated C1, C2, and C3 respectively.

The instruments used in this study consisted primarily of manometers of various types. A 2-in. Meriam inclined manometer was used across the

Table 3. Specifications of perforated sheets

| Sheet number | Hole diameter (in.) | Pitch (in.) | Open area calculated (%) | Open area observed (%) | No. of holes exposed | Gauge |
|---|---|---|---|---|---|---|
| A1 | 3/32 | 0.140 | 40.11 | 40.01 | 2920 | 22 |
| A2 | " | 0.173 | 26.73 | 26.27 | 1941 | 16 |
| A3 | " | 0.188 | 22.56 | 22.58 | 1645 | " |
| A4 | " | 0.250 | 12.76 | 12.44 | 904 | " |
| A5 | " | 0.313 | 8.15 | 8.00 | 580 | " |
| A6 | " | 0.374 | 5.61 | 5.53 | 402 | " |
| A7 | " | 0.500 | 3.19 | 3.13 | 229 | " |
| A8 | " | 0.625 | 2.02 | 2.06 | 150 | " |
| A9 | " | 0.748 | 1.43 | 1.42 | 103 | " |
| A10 | " | 1.00 | 0.793 | 0.796 | 58 | " |
| A11 | " | 1.25 | 0.510 | 0.495 | 36 | " |
| A12 | " | 1.50 | 0.354 | 0.357 | 26 | " |
| A13 | " | 2.00 | 0.199 | 0.206 | 15 | " |
| A14 | " | 2.50 | 0.128 | 0.127 | 9.25 | " |
| B1 | 3/16 | 0.281 | 40.11 | 40.26 | 733 | 16 |
| B2 | " | 0.308 | 33.44 | 33.01 | 601 | " |
| B3 | " | 0.432 | 17.00 | 17.30 | 315 | " |
| B4 | " | 0.537 | 11.00 | 11.00 | 200 | " |
| B5 | " | 0.602 | 8.24 | 8.28 | 151 | " |
| B6 | " | 0.861 | 4.28 | 4.23 | 77 | " |
| B7 | " | 1.09 | 2.67 | 2.69 | 49 | " |
| B8 | " | 1.24 | 2.06 | 2.03 | 37 | " |
| B9 | " | 1.72 | 1.07 | 1.04 | 19 | " |
| B10 | " | 2.16 | 0.70 | 0.714 | 13 | " |
| B11 | " | 2.48 | 0.515 | 0.510 | 9.3 | " |
| B11a | " | 2.48 | 0.515 | 0.495 | 9 | " |
| B12 | " | 3.45 | 0.259 | 0.261 | 4.75 | " |
| B13 | " | 4.29 | 0.172 | 0.192 | 3.5 | " |

thin plate orifice metering element. One leg of a similar Meriam inclined manometer, a 45-in. U tube manometer (local construction) and a 10-in. Meriam micromanometer were connected to a manifold; the other legs were open to atmosphere. Rubber hose was used to connect the manifold to the various pressure taps on both the plenum chamber and 8-in.-diameter column. Spring clamps were used to isolate the manometers and pressure taps. A summary of the approximate pressure range in which each manometer was used together with their least division follows:

| Range (in. of water) | Least division (in. of water) | Manometer |
|---|---|---|
| 0.0 - 0.3 | 0.001 | Micromanometer |
| 0.3 - 2.0 | 0.01 | Inclined manometer |
| 2.0 - 35.0 | 0.1 | U tube manometer |

An Airguide model 214-B barometer was used in recording atmospheric pressure. Two A.S. Lapine -30°F to 120°F thermometers were used for temperature measurements. One thermometer was modified so that wet bulb readings could be obtained. A set of Howe scales having a least division of one ounce was employed to weigh the required batches of grain.

## EXPERIMENTAL PROCEDURE

Initially, two grains, wheat and corn, were selected for use in the air resistance study. These two grains were selected because of the apparent physical differences and the fact that they are frequently stored in large quantities. Later, grain sorghum, soybeans and a long grained rice were included in the study. The tests together with the sheet series are summarized in Table 4.

Table 4. Summary of tests

| Test no. | Type of system | Sheet series | Grain |
|---|---|---|---|
| 1 | Suction | A | No grain |
| 2 | " | B | No grain |
| 3 | " | A | Corn |
| 4 | " | B | Corn |
| 5 | " | A | Wheat |
| 6 | " | B | Wheat |
| 7 | Suction and pressure | A | Corn |
| 8 | " " " | A | Wheat |
| 9 | " " " | A | Soybeans |
| 10 | " " " | A | Sorghum |
| 11 | " " " | A | Rice |

Information as to the grade and other specifications of the grains used is summarized in Table 5. In general, the grains were clean and dry.

Several methods of filling the 8-in. column with grain were investigated. Attempts were made to place the grain with a minimum of compaction. These methods were discarded because replication of the same bulk specific weight from fill to fill was difficult to achieve. Also, considerable settlement of the grain occurred particularly at the higher

Table 5. Specifications of grains used in the resistance to air flow study of perforated sheets supporting grain

| | |
|---|---|
| **Shelled yellow dent corn** | |
| Mechanical damage | 15.5% |
| Foreign material | 0.4% |
| Test weight | 54.5 lb/bu |
| Moisture content | 13.7% - 8.38% |
| Bulk specific weight for Tests 3, 4 and 7 | 45.8 $lb/ft^3$ |
| Bulk specific weight at test weight | 43.8 $lb/ft^3$ |
| Grade | No. 2 Y.C. |
| **Soft red winter wheat** | |
| Mechanical damage | 2.2% |
| Foreign material | 0.8% |
| Test weight | 59.5 lb/bu |
| Moisture content | 14.5% - 9.18% |
| Bulk specific weight for Tests 5, 6 and 8 | 49.7 $lb/ft^3$ |
| Bulk specific weight at test weight | 47.8 $lb/ft^3$ |
| Grade | No. 2 S.R.W.W. |
| **Soybeans** | |
| Mechanical damage | 3.2% |
| Foreign material | 0.2% |
| Splits | 7.4% |
| Test weight | 56.5 lb/bu |
| Moisture content | 6.05% |
| Bulk specific weight for Test 9 | 47.7 $lb/ft^3$ |
| Bulk specific weight at test weight | 45.4 $lb/ft^3$ |
| Grade | No. 3 Y.S.B. |
| **Grain sorghum** | |
| Mechanical damage | 1.8% |
| Foreign material | 0.13% |
| Test weight | 55.5 lb/bu |
| Moisture content | 10.18% |
| Bulk specific weight for Test 10 | 45.8 $lb/ft^3$ |
| Bulk specific weight at test weight | 44.6 $lb/ft^3$ |
| Grade | No. 1 R.G.S. |
| **Rough rice (Bluebonnet 50)** | |
| Mechanical damage | 0 |
| Foreign material | 0 |
| Test weight | 43.5 lb/bu |
| Moisture content | 8.08% |
| Bulk specific weight for Test 11 | 38.2 $lb/ft^3$ |
| Bulk specific weight at test weight | 35.0 $lb/ft^3$ |
| Grade | U.S. No. 1 |

air flow rates. The final method selected for filling the column consisted of weighing a specified amount of grain such that the bulk specific weight shown in Table 5 would be obtained. This grain was placed in a small hoppered bin which was elevated in such a manner that the 8-in. column could be placed under it for filling. The manner in which the column was located for filling is shown in Figure 6. The grain, upon release from the elevated bin, was allowed to fall freely into the 8-in. column until it was full. The cover plate was then tapped with a 2 lb. 14 oz. rubber-tipped hammer until the balance of the grain contained in the elevated bin could be added and the column of grain leveled, using a 1-in. diameter wooden dowel. Some experience was necessary in order to judge when compaction should be stopped so that the column would be full when leveled off. The selection of the quantity of grain to place in the 8-in. column was somewhat arbitrary. It was desired to select a quantity which would permit filling the column so that little or no settlement would occur during a complete test for the particular fill; however, overcompaction was also undesirable. Prior to selection of the bulk specific weights used, preliminary runs were made to establish the minimum bulk specific weight for negligible settlement. Table 5 shows that the bulk specific weights selected were slightly higher than the bulk specific weight at the test weight. The procedure to determine the test weight is described in the Official Grain Standards of the U. S. (20). During the tests a maximum settlement of less than 0.5 percent of the column height occurred when the column was filled with wheat. With corn the settlement was not as great.

Figure 6. Elevated bin used in filling the 8-in. diameter sheet metal column

After the column was filled with grain, it was located on the plenum chamber and bolted in place. Any grain which passed through the perforated sheet was replaced in the column and the surface releveled.

In selecting the range of air flow rates, the object was to include in the range rates which might be encountered in both ventilating and drying operations. Table 6 lists the selected air flow rates together with the equipment used to obtain them. In computing the flow rates for the turbine and for other calculations involving specific weight and viscosity of air, a mean value of 0.071 $lbs/ft^3$ and a dry bulb temperature of 78°F were used. The selection of a mean value for specific weight and dry bulb temperature would seem reasonable in view of the range of variation of these variables. The specific weight varied from 0.068 to 0.073 $lbs/ft^3$. The dry bulb temperature ranged from 64°F to 84°F. It is estimated that these simplifications would introduce a negligible error in determining viscosity and a maximum error of 2 percent in determining the air flow rate. Prior to proceeding with the test program, the complete system was thoroughly checked for air leaks and those located were sealed.

The general procedure to evaluate the apparent drop in static pressure across the perforated sheet was to install one of the perforated discs in the cover plate, seal the edge with paraffin wax and remove all excess wax from around the edge of the disc and from the wall of the mounting collar. All partial holes around the periphery of the disc were sealed with wax, with the exception of sheets A14, B11, B12 and B13, where the wax was removed from the partial holes to obtain the desired

Table 6. Air flow rates

| Run no. | Equipment | Transmission gear 3-speed | Transmission gear 4-speed | Orifice diameter (in.) | Pressure drop across the orifice (in. of water) | Apparent velocity ft/min |
|---|---|---|---|---|---|---|
| 1 | Air pump | R | R | | | 0.628 |
| 2 | " | R | 2 | | | 1.584 |
| 3 | " | R | 3 | | | 2.905 |
| 4 | " | 1 | 4 | | | 6.206 |
| 5 | Turbine | | | 0.770 | 0.25 | 11.605 |
| 6 | " | | | 0.9625 | 0.40 | 22.837 |
| 7 | " | | | 0.9625 | 1.70 | 46.791 |
| 8 | " | | | 1.347 | 1.80 | 95.129 |

open areas. The sheet metal column was located over the perforated sheet and the joint between the mounting collar and the column sealed. The column was filled with grain according to the previously described procedure. The cover plate and column were then bolted to the plenum chamber. Pressure measurements in the plenum chamber and at each pressure tap on the 8-in. column were recorded at the air flow rates shown in Table 6. Temperature and barometric pressure readings also were periodically recorded. At the completion of a series of runs at the various air flow rates, the cover plate and column of grain were removed from the plenum chamber and the grain dumped into a storage barrel. The column was refilled and the process repeated.

In determining the resistance of the perforated sheet supporting grain, the assumption was made that flow was linear through the grain to the interface of the grain and sheet. The pressure gradient through the 18-in. column of grain was plotted on ordinary graph paper. The curve was extrapolated to the zero height ordinate and the pressure at this point subtracted from the plenum chamber pressure to yield the apparent pressure drop through the perforated sheet. Figure 7 illustrates the procedure. In determining the pressure at the various points on the column and plenum chamber atmospheric pressure was used as the zero reference point.

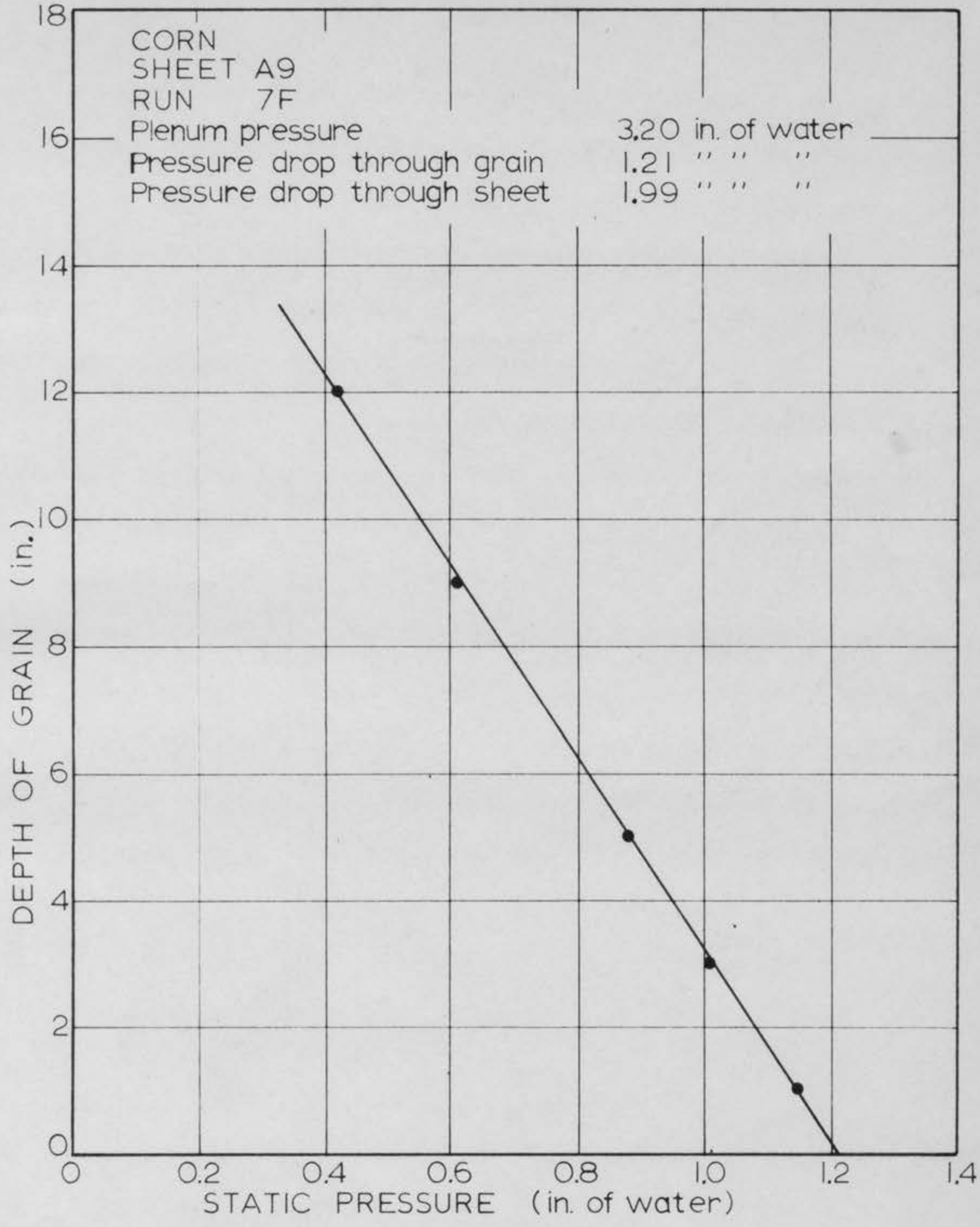



Figure 7. Pressure gradient through the 18-in. column of grain

## RESULTS AND DISCUSSION

Considerable variation in the apparent static pressure drop across the perforated sheets occurred when the cylinder of grain was emptied and refilled with the same grain. However, with the same filling and air flow rates, it was possible to reproduce observations within $\pm 5$ percent. The variation which occurred with successive fillings was attributed to the random way in which the grain was positioned in relation to the perforations in the sheet. To evaluate this variation, tests were conducted with a single 3/16-in.-diameter hole in the center of an 8-in.-diameter disc. In Table 7 the coefficient of variation, defined by Snedecor (18) as the ratio of the sample standard deviation divided by the sample mean, was used to indicate the degree of variation in the apparent static pressure drop which may occur with an individual perforation. With multiple openings the coefficient of variation was reduced. With the particular equipment and procedures used, the average values for corn and wheat with the series A and B sheets are as follows:

| Grain | Sheet series | Average coefficient of variation (%) |
|---|---|---|
| Wheat | A | 14 |
| Wheat | B | 20 |
| Corn | A | 12 |
| Corn | B | 22 |

The coefficient of variation for each series of runs at each air flow rate is included in Appendix A.

Examination of Equation 9 shows Euler number to be a function of four Pi terms. The assumption was made that G would remain constant for

Table 7. Variation in apparent static pressure drop through grain supported on a perforated sheet having a single 3/16-in.-diameter hole

| System[a] | Grain | Air flow rate cfm/ft$^2$ | Mean static pressure drop in. of water | Coefficient of variation % |
|---|---|---|---|---|
| Suction | Wheat | 0.628 | 1.675 | 45 |
| " | " | 1.584 | 2.360 | 39 |
| " | Corn | 0.628 | 0.733 | 78 |
| " | " | 1.584 | 1.083 | 82 |
| Pressure | Wheat | 0.628 | 1.485 | 46 |
| " | " | 1.584 | 2.114 | 47 |
| " | Corn | 0.628 | 0.538 | 68 |
| " | " | 1.584 | 0.738 | 64 |

[a]A suction system is defined as a system where air moves through the grain to the perforated sheet; a pressure system is the reverse.

each combination of grain and perforation diameter. To evaluate the effect of the Pi term t/d, auxiliary tests were made using the three 8-in. discs drilled with 3/16-in.-diameter holes. A description of the discs was included in the section on experimental apparatus.

The results of these tests are shown in Figures 8 and 9. Each point on these figures is the mean of the observations from a series of six runs. After each series of runs, the cylinder of grain was emptied and refilled. Examinations of the curves at the higher Reynolds numbers would indicate that in the range of value of $\pi_4$ = t/d from 0.2 to 0.7, the Euler number decreases as the value of t/d increases. This decrease was estimated to be in the order of 5 to 10 percent. Examination of the curves for the relationship between the coefficient of discharge versus t/d published by Smith and Van Winkle (17) shows that for a Reynolds

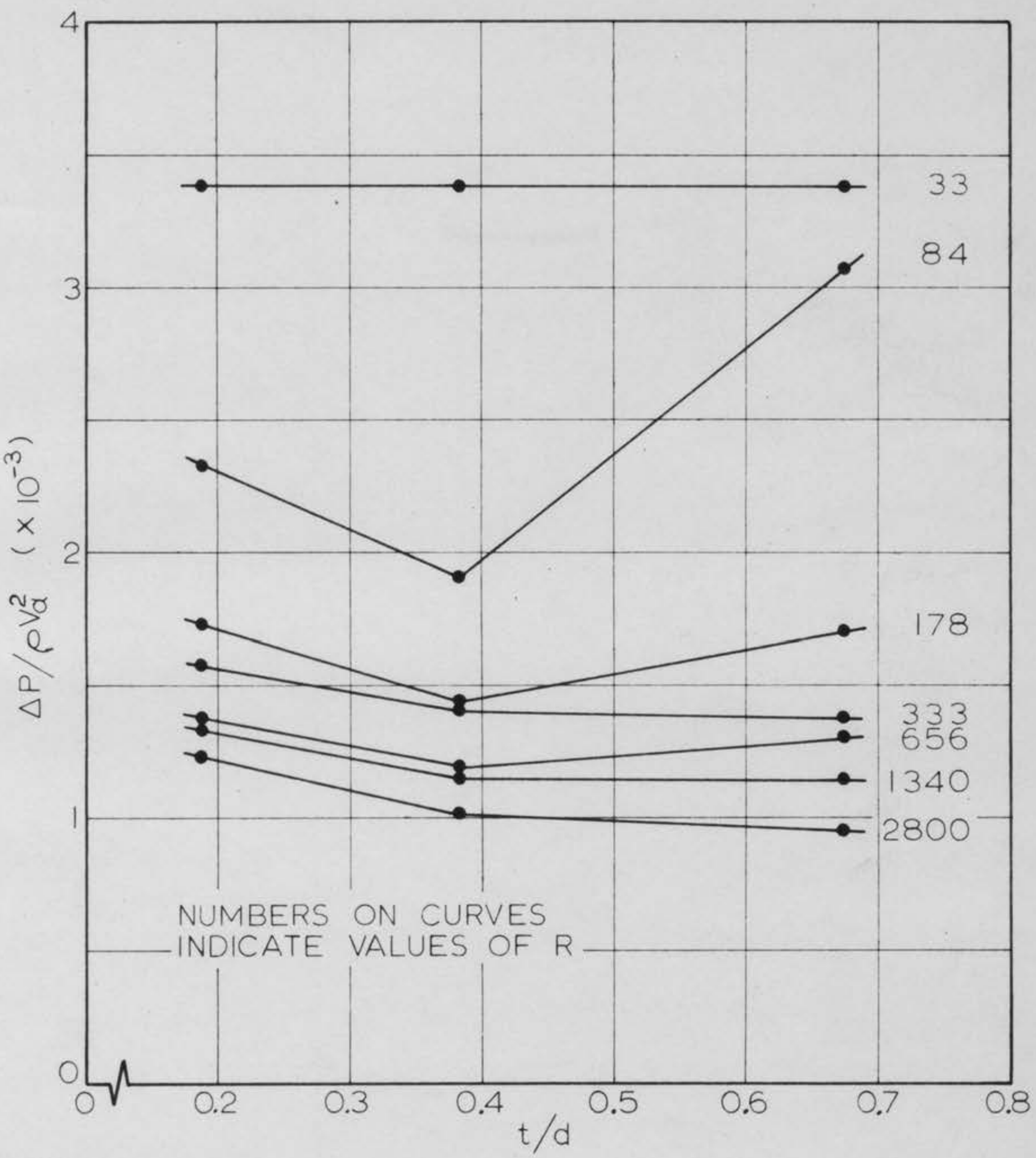



Figure 8. Relationship between Euler number and t/d for perforated sheets supporting corn

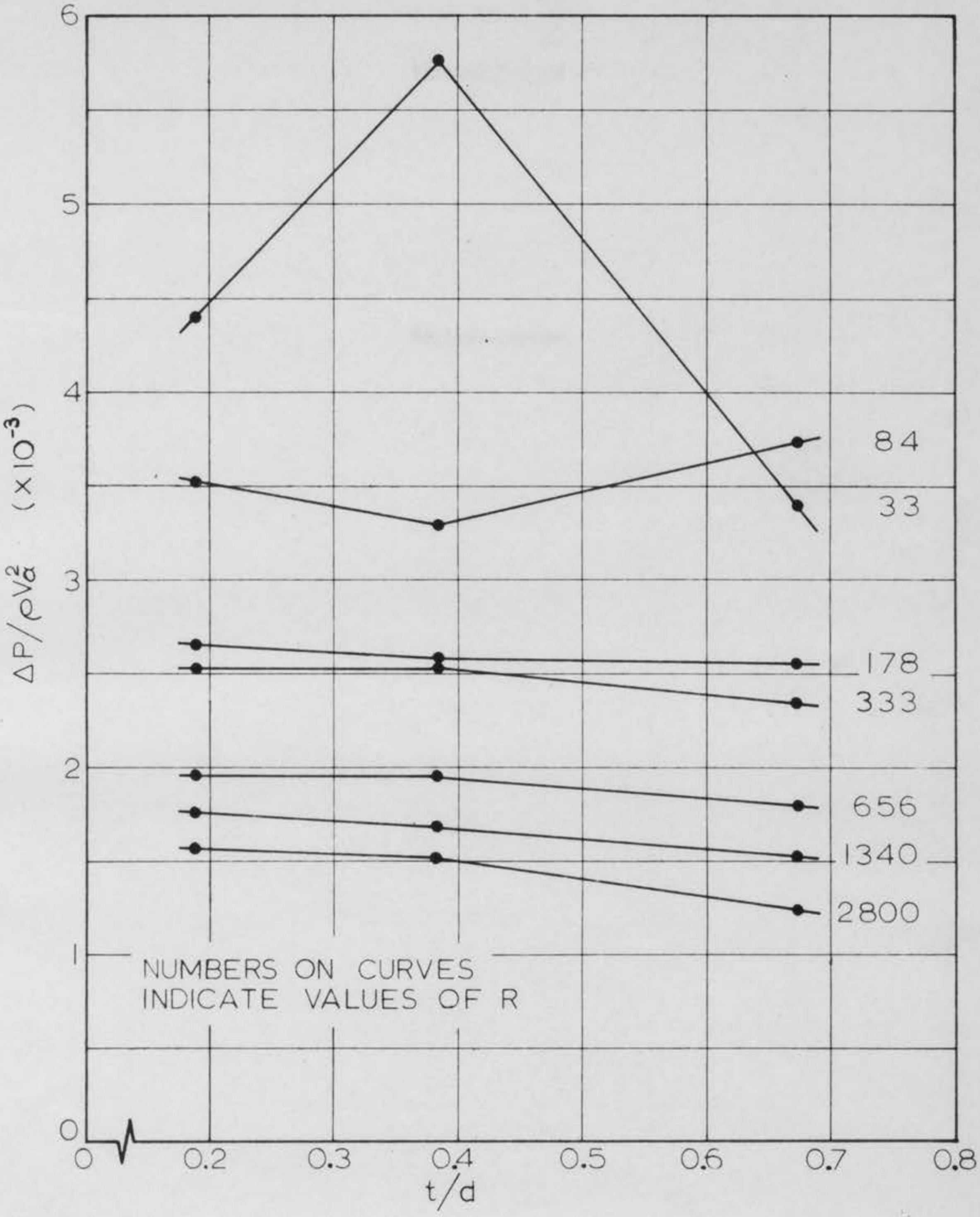



Figure 9. Relationship between Euler number and t/d for perforated sheets supporting wheat

number of 600 the coefficient of discharge increases 4.7 percent as the value of t/d increases from 0.2 to 0.7. Rearranging Equation 5 thus

$$\Delta P/\rho V_a^{\ 2} \ = \ 1\text{-}F^2/2F^2C_d^{\ 2}$$

it can be shown that for a constant value of F an increase in the coefficient of discharge of 4.7 percent would result in a decrease of 9.6 percent in the equivalent value of the Euler number. The work performed by Smith and Van Winkle (17) would tend to confirm the conclusion that in the range of t/d of 0.2 to 0.7, an increase in the value of t/d may result in a small decrease in the Euler number.

Using Equation 9 to develop a correlation, plots were constructed on log paper of Euler number versus Reynolds number for the various values of F. The Pi terms t/d and G were considered constant for each combination of grain and sheet series. The diameter of the perforations in each sheet together with the average velocity through the perforations was used to calculate Reynolds number. Tests 1 and 2 were made with no grain covering the sheet; Tests 3 and 4 were made with corn; and 5 and 6 with wheat.

Proceeding on the assumption that G and t/d are constant, therefore:

$$\Delta P/\rho V_a^{\ 2} \ = \ f(R,F) \tag{10}$$

The next step was to determine how the latter two Pi terms may be combined. A test for combination by multiplication was applied as follows:

Let $\pi_1 = \Delta P/\rho V_a^2$ Euler number

$\pi_2 = \rho Vd/12\mu$ Reynolds number

$\pi_3 = F$ Ratio of open area of the perforated sheet to the total area.

Using the data for Test 3, the log of Euler number was plotted against the log of Reynolds number for each value of F (Figure 12). Curves were fitted to the experimental points. Since the curves appear to break upward at a Reynolds number of 300, the empirical curves were broken into two sections and relationships developed for each part. The observed points for that section of the curve where Reynolds number is greater than 300 approximate straight parallel lines having a slope of -0.07. The relationship between $\pi_1$ and $\pi_2$ for any two fixed values of $\pi_3$ may be expressed as:

$$\pi_{1\bar{3}} = f(\pi_2\bar{\pi}_3) = B\pi_2^{-0.07} \qquad (11)$$

$$\pi_{1\bar{\bar{3}}} = f(\pi_2\bar{\bar{\pi}}_3) = B'\pi_2^{-0.07} \qquad (12)$$

where the values of the constants B and B' depend upon the values selected for $\bar{\pi}_3$ and $\bar{\bar{\pi}}_3$. If $\pi_2$ and $\pi_3$ can be combined by multiplication, the following relationship must hold (10),

$$f(\pi_2\overline{\pi}_3)/f(\overline{\pi}_2\overline{\pi}_3) = f(\pi_2\overline{\overline{\pi}}_3)/f(\overline{\pi}_2\overline{\overline{\pi}}_3) \qquad (13)$$

$\overline{\pi}_2$ was chosen at 1000.

Substituting Equations 11 and 12 in 13 yields:

$$B\pi_2^{-0.07}/B(1000)^{-0.07} = B'\pi_2^{-0.07}/B'(1000)^{-0.07} \qquad (14)$$

Since Equation 14 is an identity, combination by multiplication is possible.

To establish the relationship between Euler number and F, a plot was constructed on log paper of Euler number versus F with Reynolds number held constant (Figure 13). Since this curve also approximates a straight line, the relationship may be expressed as:

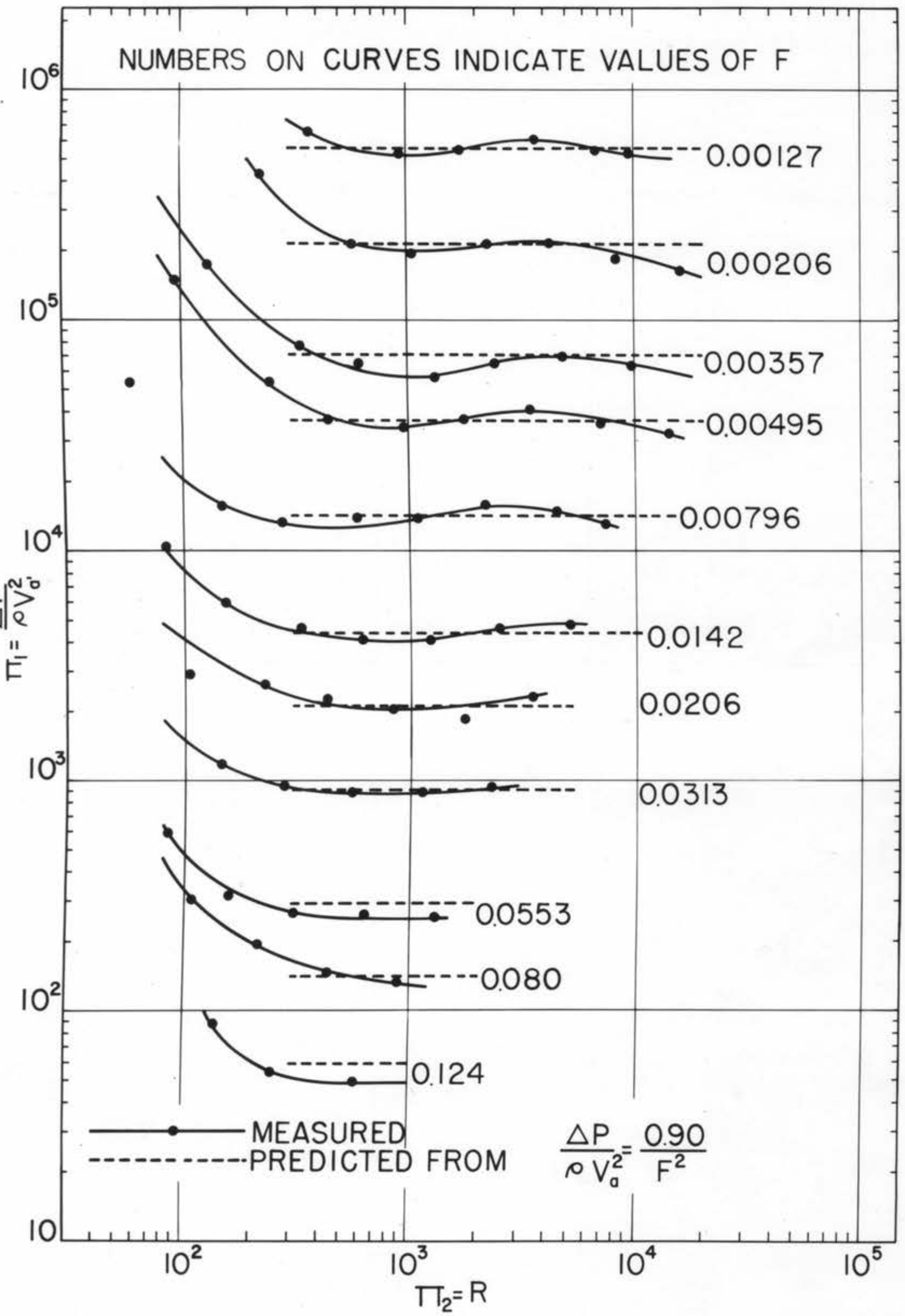
$$\pi_1 = f(\overline{\pi}_2\pi_3) = 1.60\ F^{-2},\ \text{for}\ \overline{\pi}_2 = 1000 \qquad (15)$$

The prediction equation becomes

$$\Delta P/\rho V_a{}^2 = 2.60/R^{0.07}\ F^2 \qquad (16)$$

A similar procedure was used for that portion of the curves where Reynolds number was less than 300. Curves were plotted and equations developed for each of the tests conducted. Figures 10, 11, 12, 14, 15 and 16 are plots on log paper of Euler number versus Reynolds number for Tests 1 through 6. Each point on the figure represents the mean of the observations obtained from a series of six runs, the grain column being

Figure 10. Relationship between Euler number and Reynolds number for Test 1



NUMBERS ON CURVES INDICATE VALUES OF F
0.00127
0.00206
0.00357
0.00495
0.00796
0.0142
0.0206
0.0313
0.0553
0.080
0.124
MEASURED
PREDICTED FROM $\frac{\Delta P}{\rho V_a^2} = \frac{0.90}{F^2}$
$\Pi_1 = \frac{\Delta P}{\rho V_a^2}$
$\Pi_2 = R$
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$10^2$
$10^3$
$10^4$
$10^5$

Figure 11. Relationship between Euler number and Reynolds number for Test 2

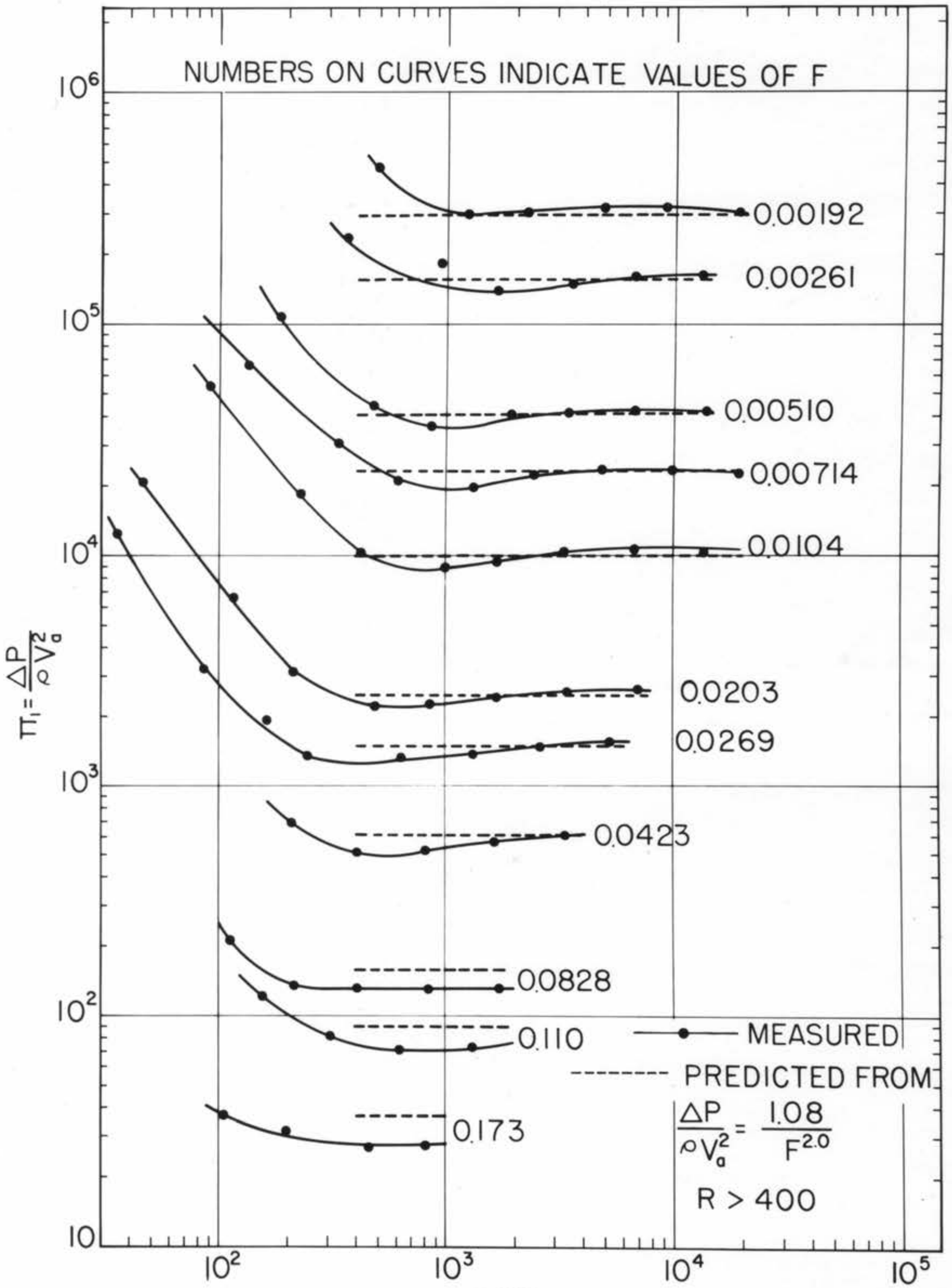
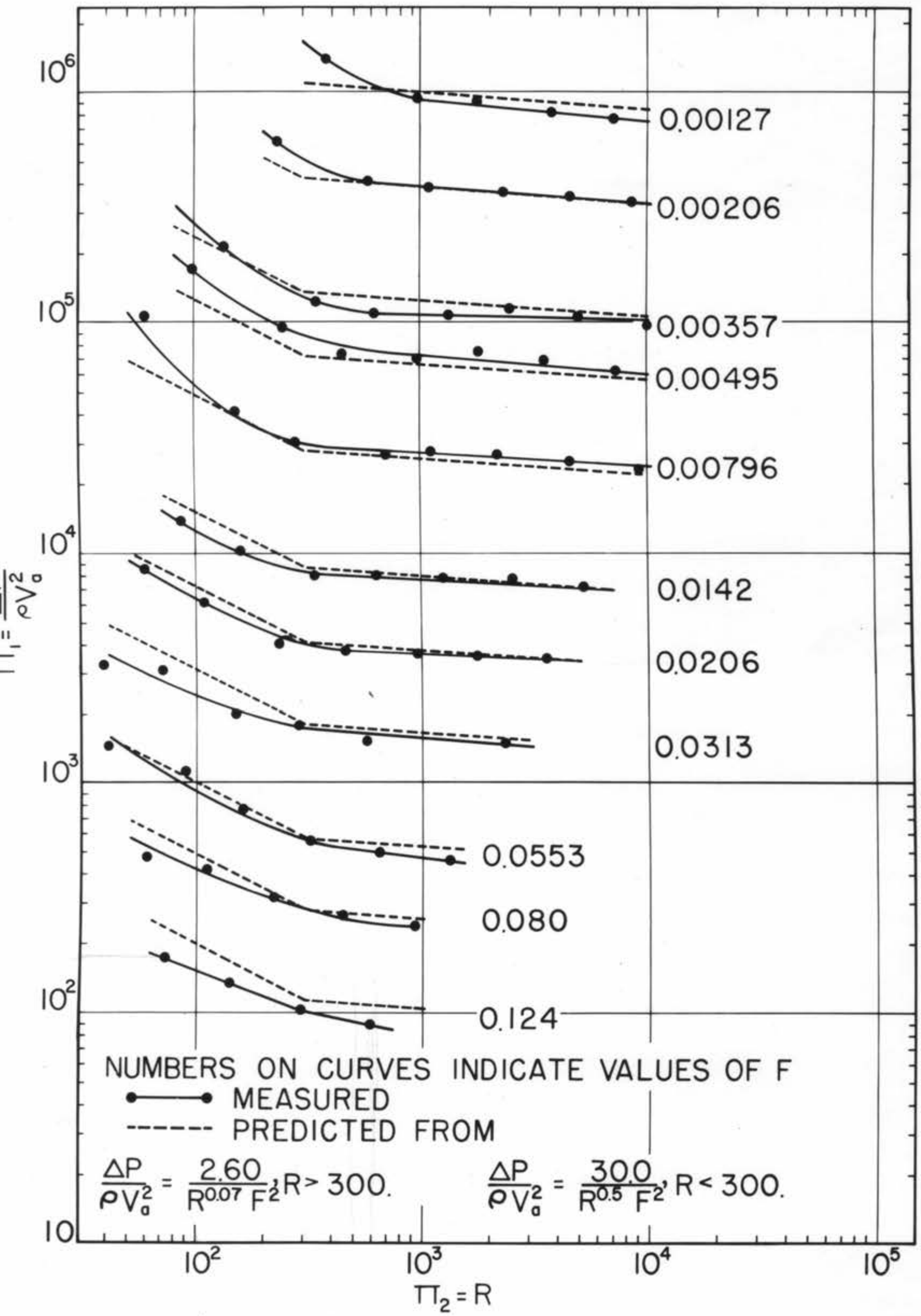

NUMBERS ON CURVES INDICATE VALUES OF F
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$\pi_1 = \frac{\Delta P}{\rho V_a^2}$
0.00192
0.00261
0.00510
0.00714
0.0104
0.0203
0.0269
0.0423
0.0828
0.110
0.173
MEASURED
PREDICTED FROM
$\frac{\Delta P}{\rho V_a^2} = \frac{1.08}{F^{2.0}}$
R > 400
$10^2$
$10^3$
$10^4$
$10^5$
$\pi_2 = R$

Figure 12. Relationship between Euler number and Reynolds number for Test 3

(Corn supported on perforated sheets having 3/32-in. diameter holes.)



$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$\Pi_1 = \frac{\Delta P}{\rho V_a^2}$
0.00127
0.00206
0.00357
0.00495
0.00796
0.0142
0.0206
0.0313
0.0553
0.080
0.124
NUMBERS ON CURVES INDICATE VALUES OF F
MEASURED
PREDICTED FROM
$\frac{\Delta P}{\rho V_a^2} = \frac{2.60}{R^{0.07} F^2}, R > 300.$
$\frac{\Delta P}{\rho V_a^2} = \frac{30.0}{R^{0.5} F^2}, R < 300.$
$10^2$
$10^3$
$10^4$
$10^5$
$\Pi_2 = R$

Figure 13. Relationship between Euler number and F for Test 3

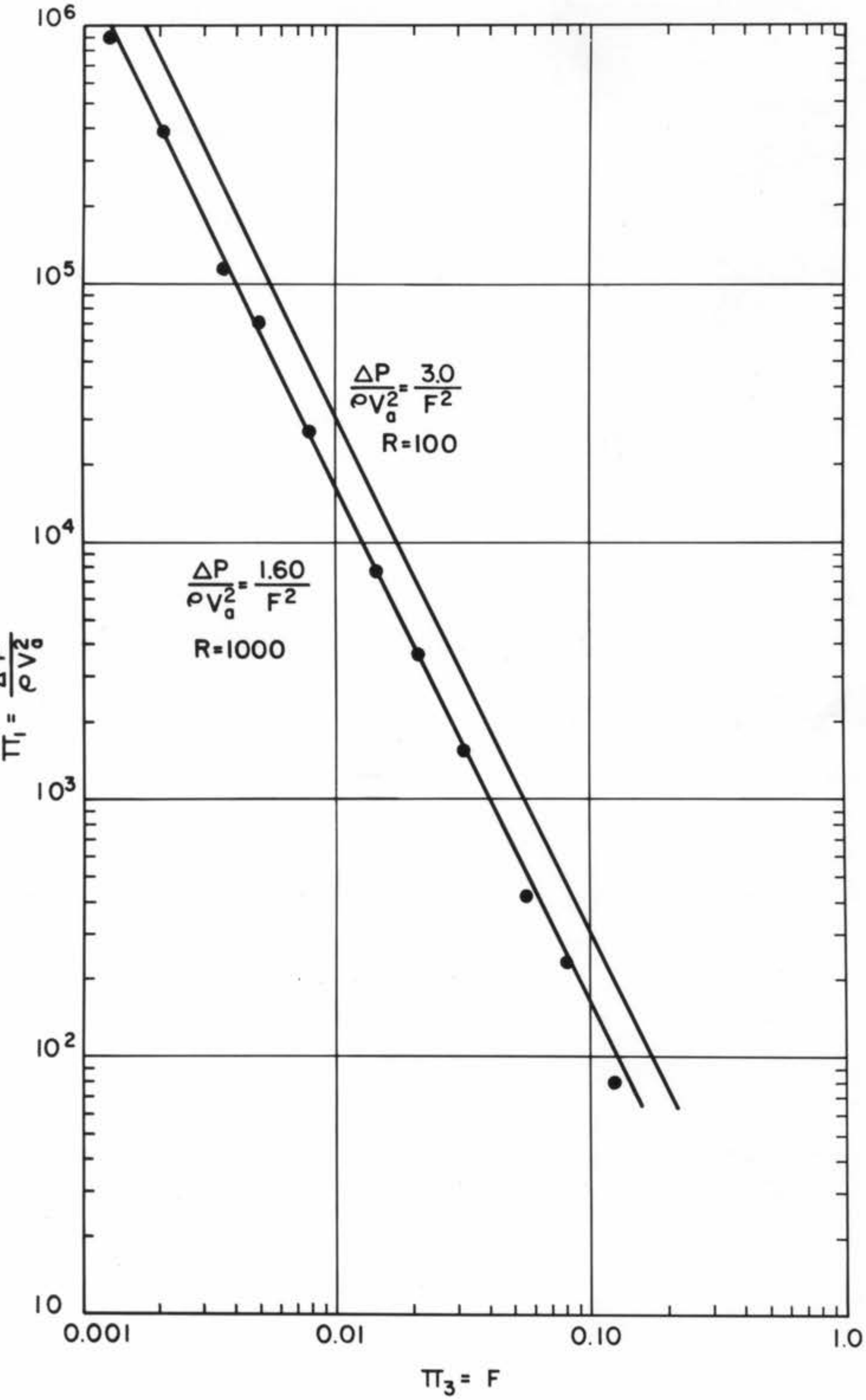
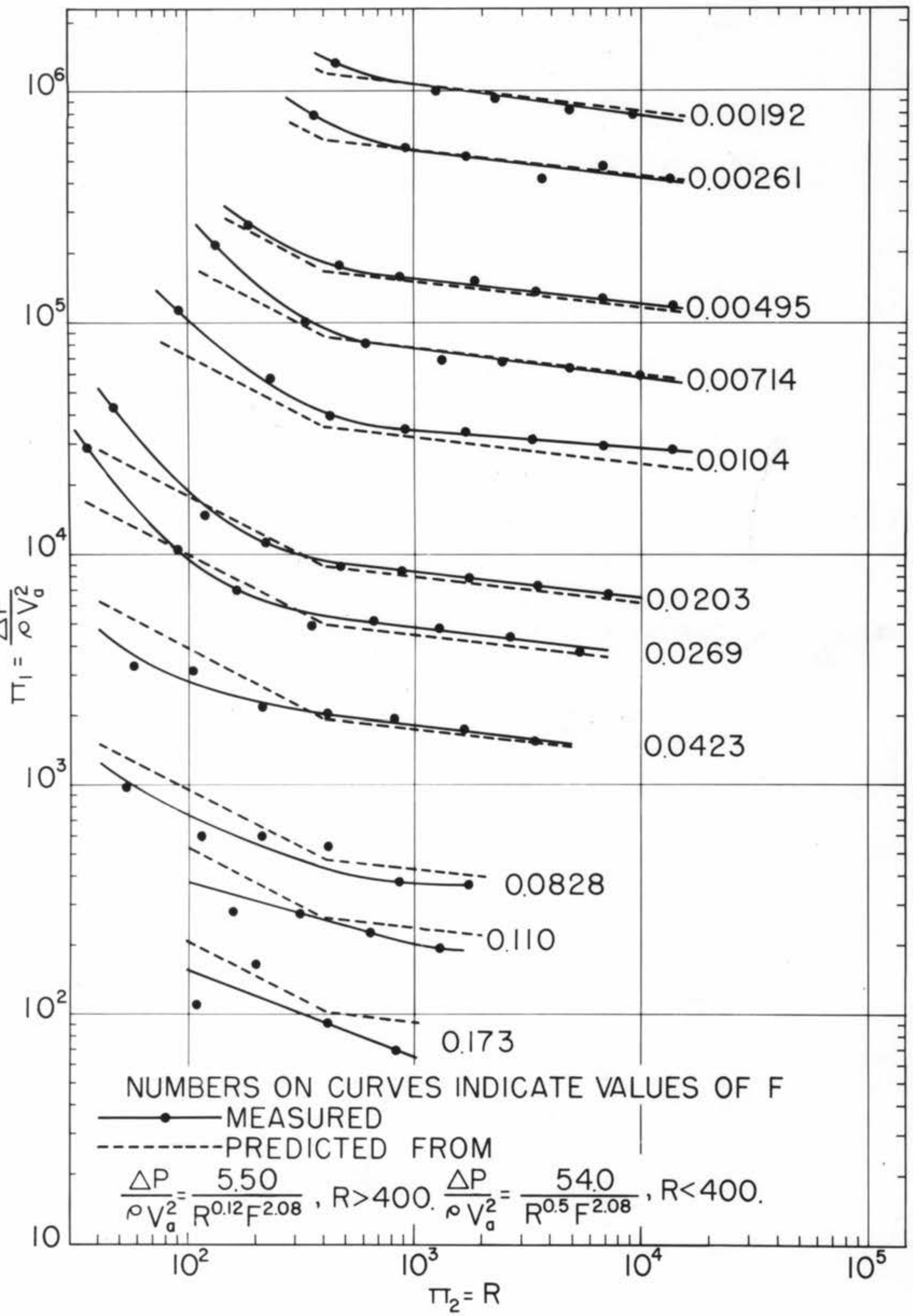

$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
0.001
0.01
0.10
1.0
$\frac{\Delta P}{\rho V_a^2} = \frac{3.0}{F^2}$
R=100
$\frac{\Delta P}{\rho V_a^2} = \frac{1.60}{F^2}$
R=1000
$\Pi_1 = \frac{\Delta P}{\rho V_a^2}$
$\Pi_3 = F$

Figure 14. Relationship between Euler number and Reynolds number for Test 4

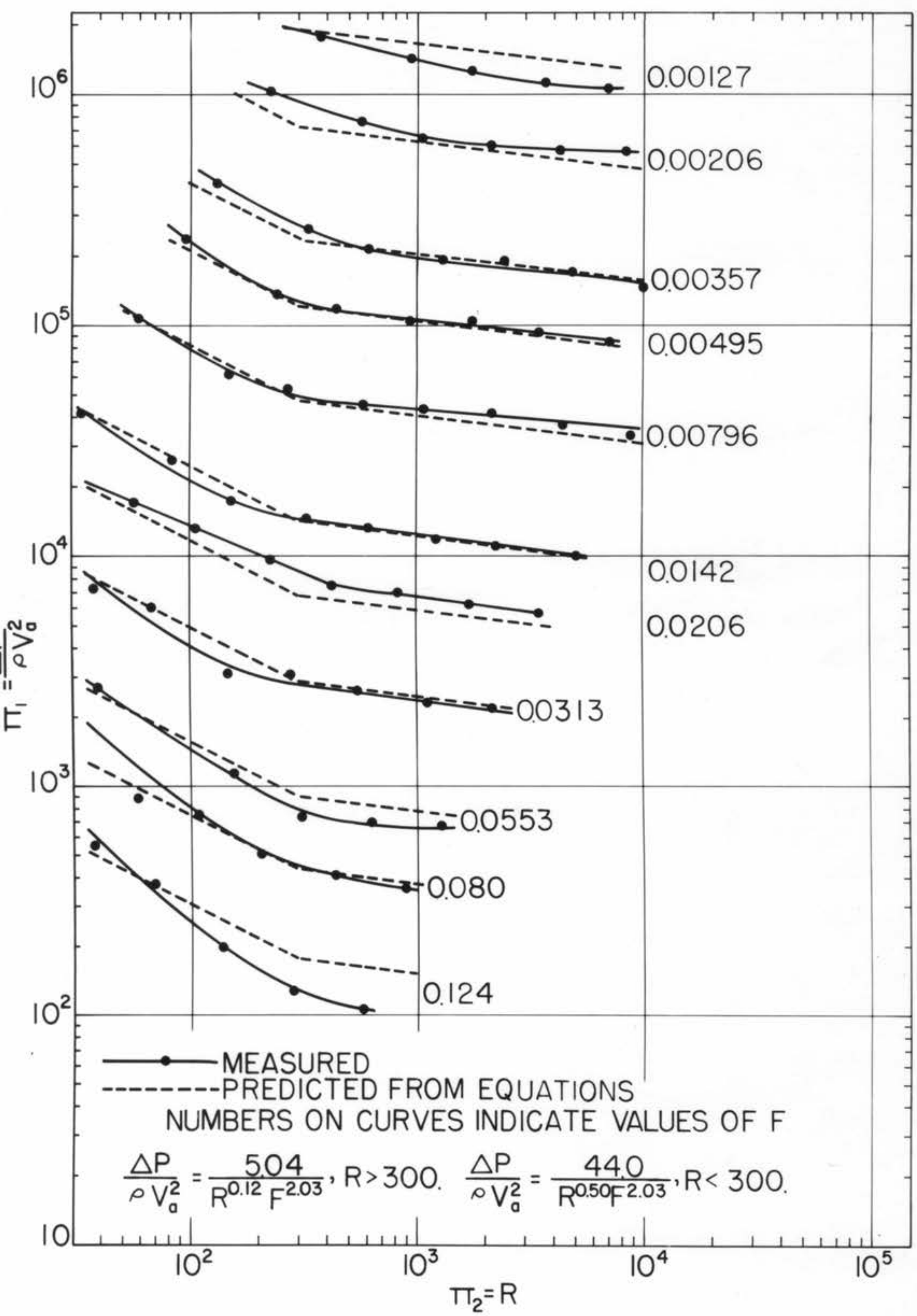
(Corn supported on perforated sheets having 3/16-in. diameter holes.)



$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$\pi_1 = \frac{\Delta P}{\rho V_a^2}$
0.00192
0.00261
0.00495
0.00714
0.0104
0.0203
0.0269
0.0423
0.0828
0.110
0.173
NUMBERS ON CURVES INDICATE VALUES OF F
MEASURED
PREDICTED FROM
$\frac{\Delta P}{\rho V_a^2} = \frac{5.50}{R^{0.12} F^{2.08}}$, R>400. $\frac{\Delta P}{\rho V_a^2} = \frac{54.0}{R^{0.5} F^{2.08}}$, R<400.
$10^2$
$10^3$
$10^4$
$10^5$
$\pi_2 = R$

Figure 15. Relationship between Euler number and Reynolds number for Test 5

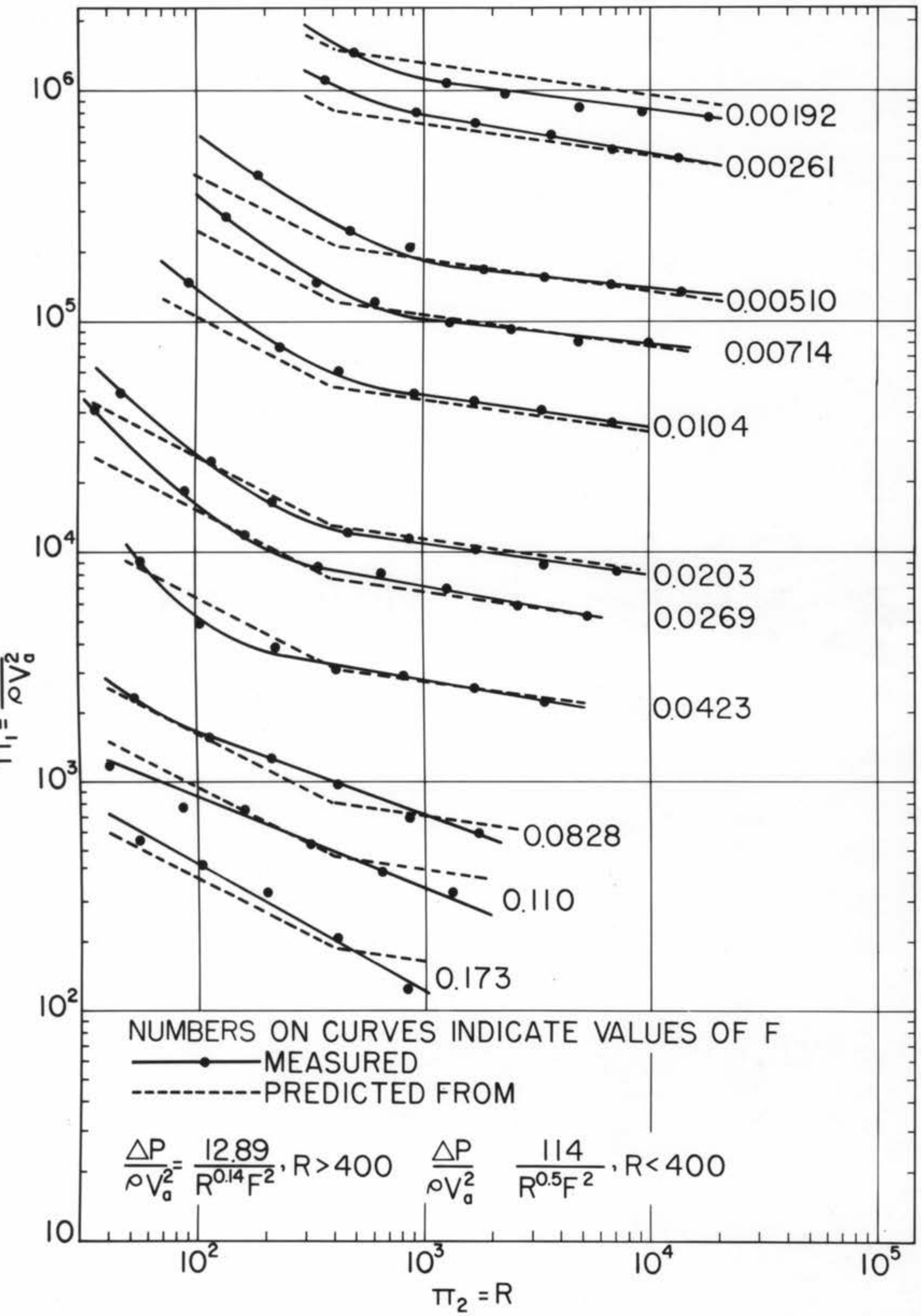
(Wheat supported on perforated sheets having 3/32-in. diameter holes.)



0.00127
0.00206
0.00357
0.00495
0.00796
0.0142
0.0206
0.0313
0.0553
0.080
0.124
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$\pi_1 = \frac{\Delta P}{\rho V_a^2}$
$10^2$
$10^3$
$10^4$
$10^5$
$\pi_2 = R$
MEASURED
PREDICTED FROM EQUATIONS
NUMBERS ON CURVES INDICATE VALUES OF F
$\frac{\Delta P}{\rho V_a^2} = \frac{504}{R^{0.12} F^{2.03}}$, $R > 300$.
$\frac{\Delta P}{\rho V_a^2} = \frac{44.0}{R^{0.50} F^{2.03}}$, $R < 300$.

Figure 16. Relationship between Euler number and Reynolds number for Test 6

(Wheat supported on perforated sheets having 3/16-in. diameter holes.)



$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$10^2$
$10^3$
$10^4$
$10^5$
$\pi_1 = \frac{\Delta P}{\rho V_a^2}$
$\pi_2 = R$
0.00192
0.00261
0.00510
0.00714
0.0104
0.0203
0.0269
0.0423
0.0828
0.110
0.173
NUMBERS ON CURVES INDICATE VALUES OF F
MEASURED
PREDICTED FROM
$\frac{\Delta P}{\rho V_a^2} = \frac{12.89}{R^{0.14} F^2}$, R>400
$\frac{\Delta P}{\rho V_a^2}$ $\frac{114}{R^{0.5} F^2}$, R<400

emptied and refilled for each run.

Expressing the relationship for Euler number, Reynolds number and F in the form,

$$\Delta P/\rho V_a^{\,2} = C/R^n F^k \qquad (17)$$

Table 8 indicates the values of the coefficient and exponents for the various combinations of grain and perforated sheets.

Table 8. Coefficients and exponents for use with Equation 17 for Tests 1 through 6

| Test no. | Diameter of perforation (in.) | Grain | C | n | k | R |
|---|---|---|---|---|---|---|
| 1 | 3/32 | No grain | 0.90 | 0.00 | 2.00 | >300 |
| 2 | 3/16 | No grain | 1.08 | 0.00 | 2.00 | >400 |
| 3 | 3/32 | Corn | 2.60 | 0.07 | 2.00 | >300 |
| 4 | 3/16 | Corn | 5.50 | 0.12 | 2.08 | >400 |
| 5 | 3/32 | Wheat | 5.04 | 0.12 | 2.03 | >300 |
| 6 | 3/16 | Wheat | 12.89 | 0.14 | 2.00 | >400 |
| 1 | 3/32 | No grain | | | | |
| 2 | 3/16 | No grain | | | | |
| 3 | 3/32 | Corn | 30.00 | 0.50 | 2.00 | <300 |
| 4 | 3/16 | Corn | 54.00 | 0.50 | 2.08 | <400 |
| 5 | 3/32 | Wheat | 44.00 | 0.50 | 2.03 | <300 |
| 6 | 3/16 | Wheat | 114.00 | 0.50 | 2.00 | <400 |

To more easily analyze the influence on the apparent pressure drop through the perforated sheets by covering them with grain or changing the diameter of the perforation, the prediction equations may be written in the form

$$\Delta P = \frac{C\rho\, V_a^{\,2}}{(\rho V d/12\mu)^n\, F^k} \tag{18}$$

Since $V = V_a/F$

$$\Delta P = \frac{C\rho\, V_a^{\,2-n}}{(\rho d/12\mu)^n\, F^{k-n}} \tag{19}$$

Assuming values for $\rho$ and $\mu$ of $2.2 \times 10^{-3}$ slugs/ft$^3$ and $3.82 \times 10^{-7}$ lb sec/ft$^2$ respectively, Equation 19 becomes

$$\Delta P = \frac{C'\, V_a^{\,b}}{F^m} \tag{20}$$

The assumption of the above values for $\rho$ and $\mu$ is reasonable since they will approximate air conditions with sufficient accuracy for the design of grain ventilation systems.

Table 9 contains a summary of the coefficients and exponents for use with Equation 20 for Tests 1 through 6.

On completion of Tests 1 through 6, it was apparent that the relationship of Euler number, Reynolds number and F could be approximated by a simple expression for the range of Pi terms involved. Five additional tests were then conducted on a reduced number of perforated sheets. Five of the series A sheets were selected and tests made using corn, wheat, soybeans, grain sorghum and rice. Corn and wheat were included in this set of tests to evaluate the ability to reproduce the data. Figures 17 and 18 show that reasonable reproduction is possible. In the above figures the broken line represents the expressions developed in

Table 9. Coefficients and exponents for use with Equation 20 for Tests 1 through 6

| Test no. | Diameter of perforation (in.) | Grain | C' | b | m | R |
|---|---|---|---|---|---|---|
| 1 | 3/32 | No grain | $1.98 \times 10^{-3}$ | 2.00 | 2.00 | >300 |
| 2 | 3/16 | No grain | 2.38 " | 2.00 | 2.00 | >400 |
| 3 | 3/32 | Corn | 4.39 " | 1.93 | 1.93 | >300 |
| 4 | 3/16 | Corn | 7.06 " | 1.88 | 1.96 | >400 |
| 5 | 3/32 | Wheat | 7.03 " | 1.88 | 1.91 | >300 |
| 6 | 3/16 | Wheat | 15.10 " | 1.86 | 1.86 | >400 |
| 1 | 3/32 | No grain | | | | |
| 2 | 3/16 | No grain | | | | |
| 3 | 3/32 | Corn | $9.84 \times 10^{-3}$ | 1.50 | 1.50 | <300 |
| 4 | 3/16 | Corn | 12.50 " | 1.50 | 1.58 | <400 |
| 5 | 3/32 | Wheat | 14.42 " | 1.50 | 1.53 | <300 |
| 6 | 3/16 | Wheat | 26.40 " | 1.50 | 1.50 | <400 |

Tests 3 and 5.

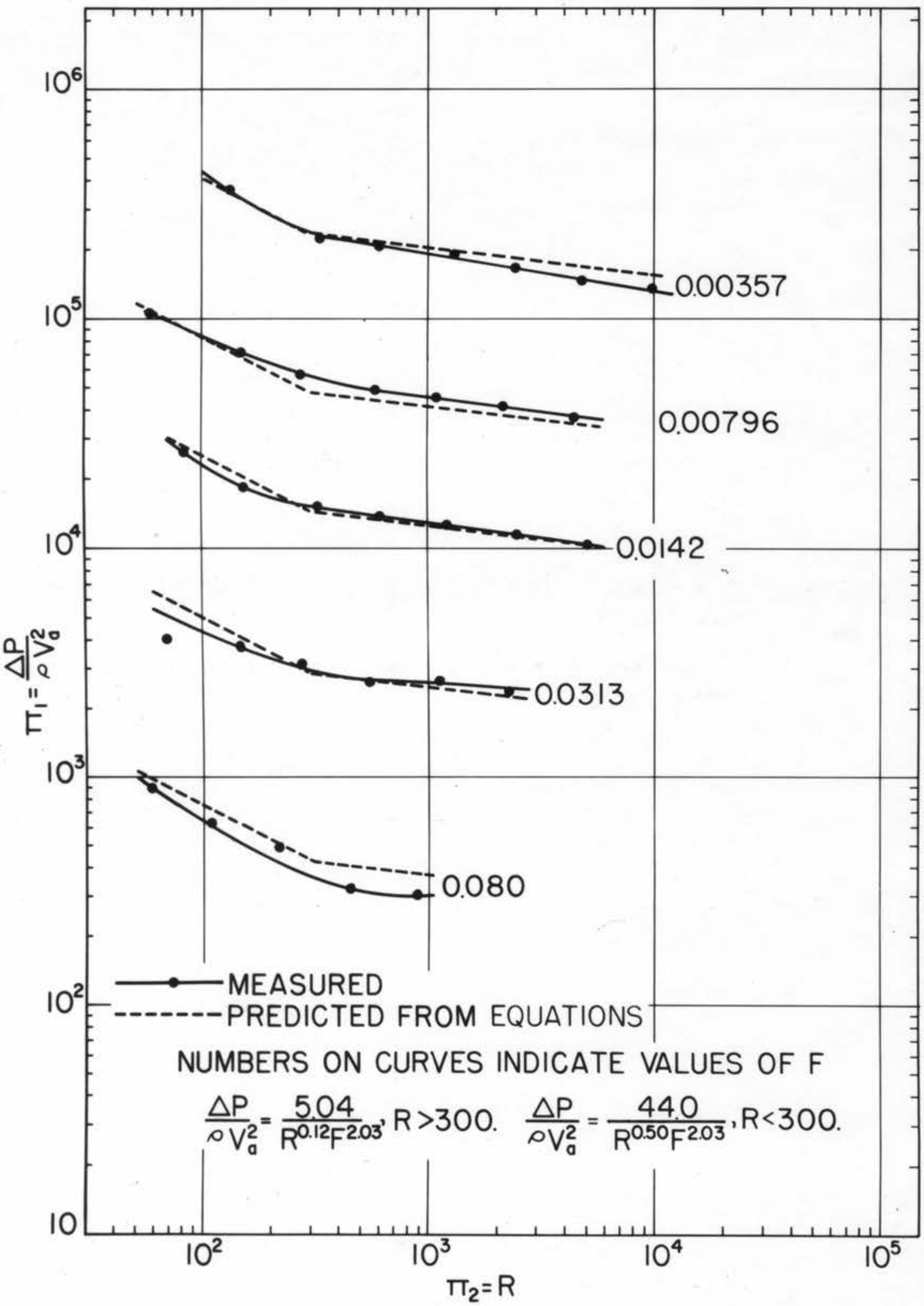
Tests 9, 10 and 11 were performed using soybeans, grain sorghum and rice. Table 10 contains values for the coefficients and exponents to be used in Equation 17 for the above tests. Data for the evaluation of the apparent pressure drop using Equation 20 is contained in Table 11.

Table 10. Coefficients and exponents for use with Equation 17 for Tests 9, 10 and 11

| Test no. | Diameter of perforation (in.) | Grain | C | n | k | R |
|---|---|---|---|---|---|---|
| 9 | 3/32 | Soybeans | 1.40 | 0 | 2.00 | >300 |
| 10 | 3/32 | Sorghum | 3.75 | 0.11 | 2.06 | >300 |
| 11 | 3/32 | Rice | 4.17 | 0.11 | 2.00 | >300 |
| 9 | 3/32 | Soybeans | 24.23 | 0.50 | 2.00 | <300 |
| 10 | 3/32 | Sorghum | 35.00 | 0.50 | 2.06 | <300 |
| 11 | 3/32 | Rice | 40.60 | 0.50 | 2.00 | <300 |

Figure 17. Relationship between Euler number and Reynolds number for Test 7

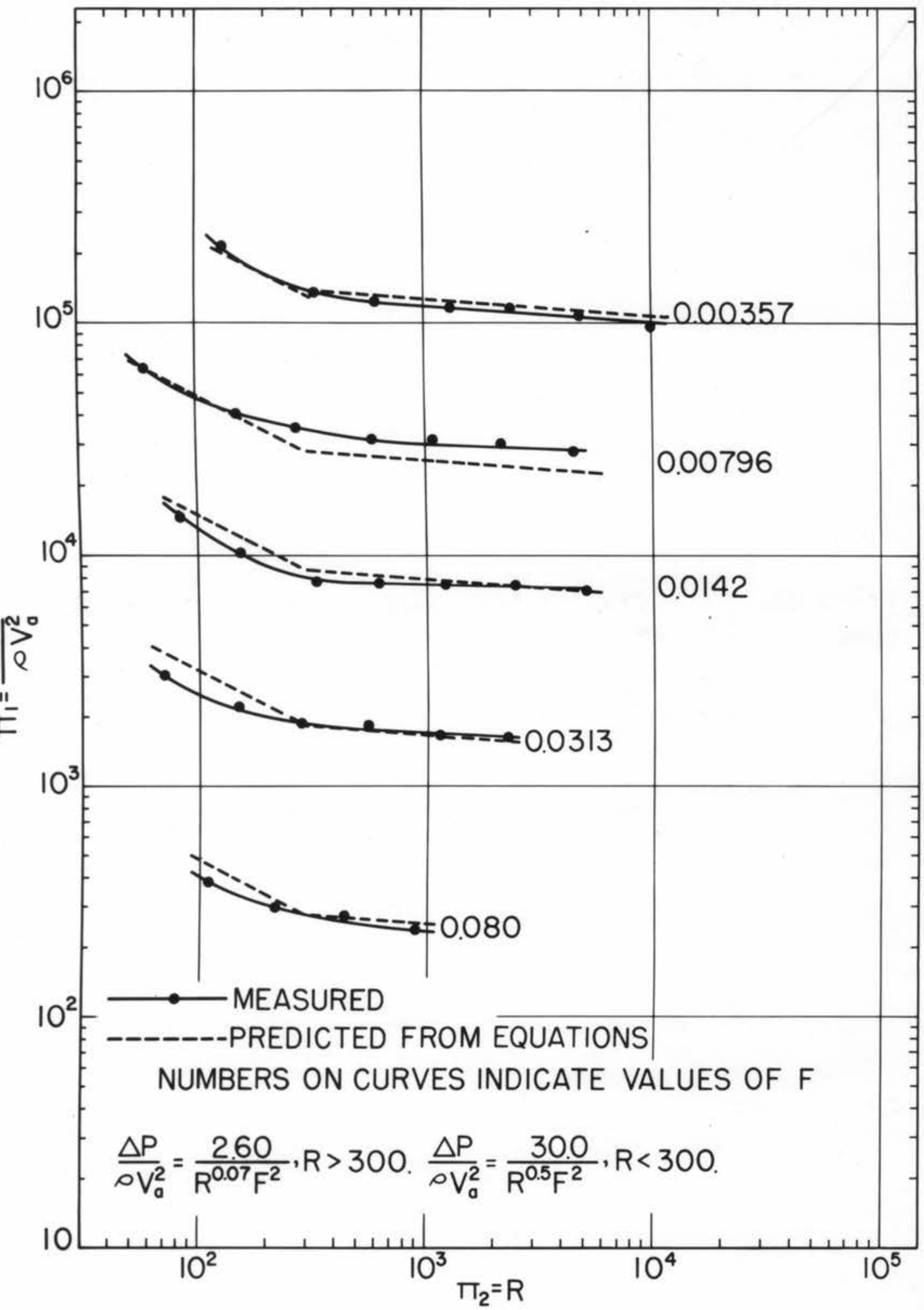
(Corn supported on perforated sheets having 3/32-in. diameter holes.)



$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$10^2$
$10^3$
$10^4$
$10^5$
$\pi_1 = \frac{\Delta P}{\rho V_a^2}$
$\pi_2 = R$
0.00357
0.00796
0.0142
0.0313
0.080
MEASURED
PREDICTED FROM EQUATIONS
NUMBERS ON CURVES INDICATE VALUES OF F
$\frac{\Delta P}{\rho V_a^2} = \frac{5.04}{R^{0.12} F^{2.03}}$, R > 300.
$\frac{\Delta P}{\rho V_a^2} = \frac{44.0}{R^{0.50} F^{2.03}}$, R < 300.

Figure 18. Relationship between Euler number and Reynolds number for Test 8

(Wheat supported on perforated sheets having 3/32-in. diameter holes.)



$\pi_1 = \frac{\Delta P}{\rho V_a^2}$
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$10^2$
$10^3$
$10^4$
$10^5$
$\pi_2 = R$
0.00357
0.00796
0.0142
0.0313
0.080
MEASURED
PREDICTED FROM EQUATIONS
NUMBERS ON CURVES INDICATE VALUES OF F
$\frac{\Delta P}{\rho V_a^2} = \frac{2.60}{R^{0.07} F^2}, R > 300.$ $\frac{\Delta P}{\rho V_a^2} = \frac{30.0}{R^{0.5} F^2}, R < 300.$

Table 11. Coefficients and exponents for use with Equation 20 for Tests 9, 10 and 11

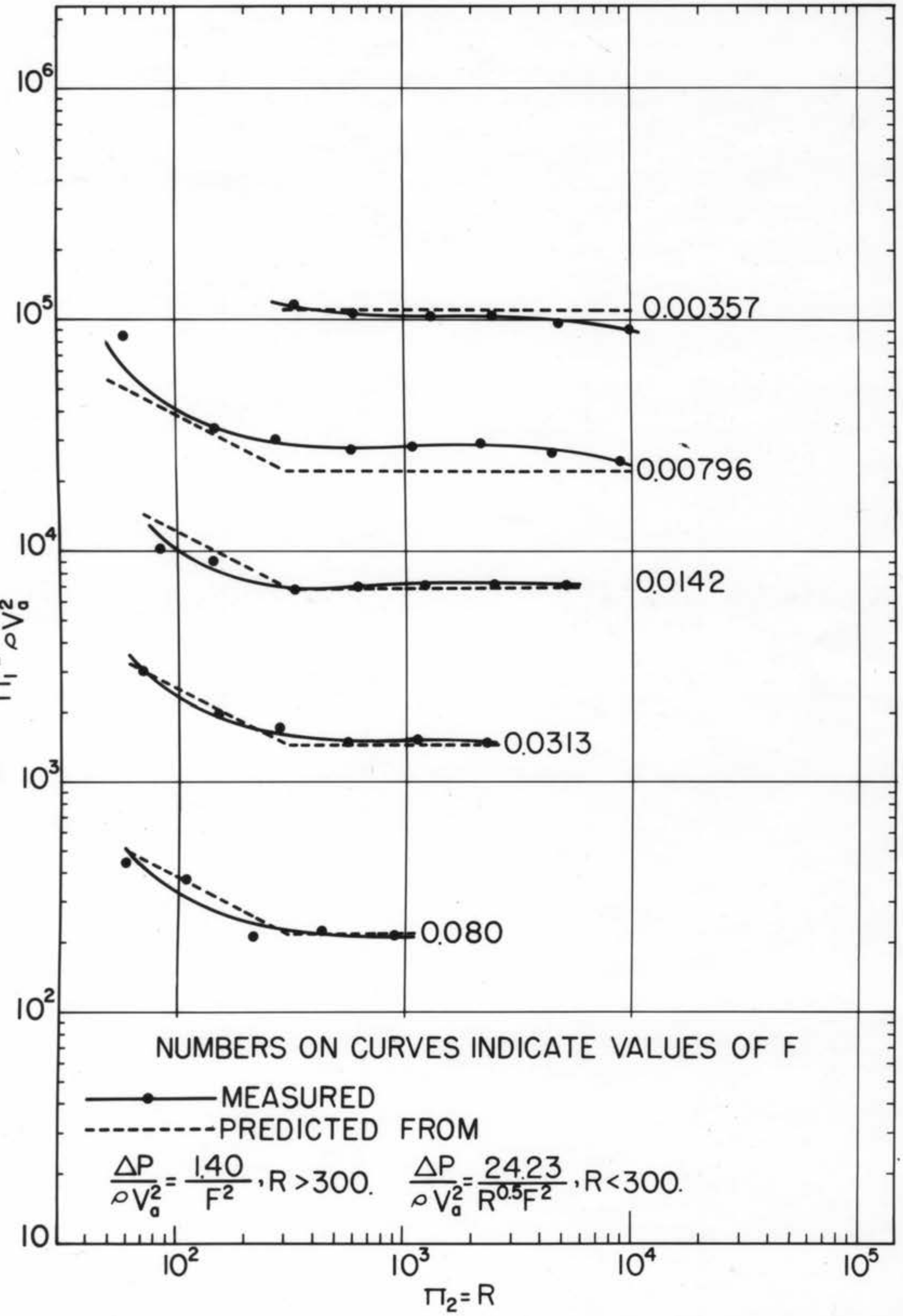
| Test no. | Diameter of perforation (in.) | Grain | C' | b | m | R |
|---|---|---|---|---|---|---|
| 9 | 3/32 | Soybeans | $3.09 \times 10^{-3}$ | 2.00 | 2.00 | >300 |
| 10 | 3/32 | Sorghum | 5.44 " | 1.89 | 1.95 | >300 |
| 11 | 3/32 | Rice | 6.04 " | 1.89 | 1.89 | >300 |
| 9 | 3/32 | Soybeans | $7.95 \times 10^{-3}$ | 1.50 | 1.50 | <300 |
| 10 | 3/32 | Sorghum | 11.50 " | 1.50 | 1.56 | <300 |
| 11 | 3/32 | Rice | 13.34 " | 1.50 | 1.50 | <300 |

Figures 19, 20 and 21 show the relationship for Euler number versus Reynolds number for Tests 9, 10 and 11.

Comparing the values of C' in Table 9, an estimate may be made of the influence of the grain and size of the perforation on the apparent static pressure drop through the perforated sheet. Comparing Test 1 with Tests 3 and 5 and Test 2 with 4 and 6, the effect is shown of placing a bed of grain on the sheet. Grain placed on the sheet increases the apparent static pressure drop across the sheet. The added resistance may be attributed to the reduction in the effective open area of the perforated sheet by kernels of grain and secondly, to the increased resistance due to non-linear flow as the air approaches the perforations. Comparison of Tests 1 and 2, 3 and 4, and 5 and 6 shows the influence of perforation size. Increasing the diameter of the perforations from 3/32 in. to 3/16 in. resulted in a 20.2 percent increase in static pressure drop for the sheets with no covering of grain. Covering the sheets with grain resulted in a considerably greater increase in static pressure drop

Figure 19. Relationship between Euler number and Reynolds number for Test 9

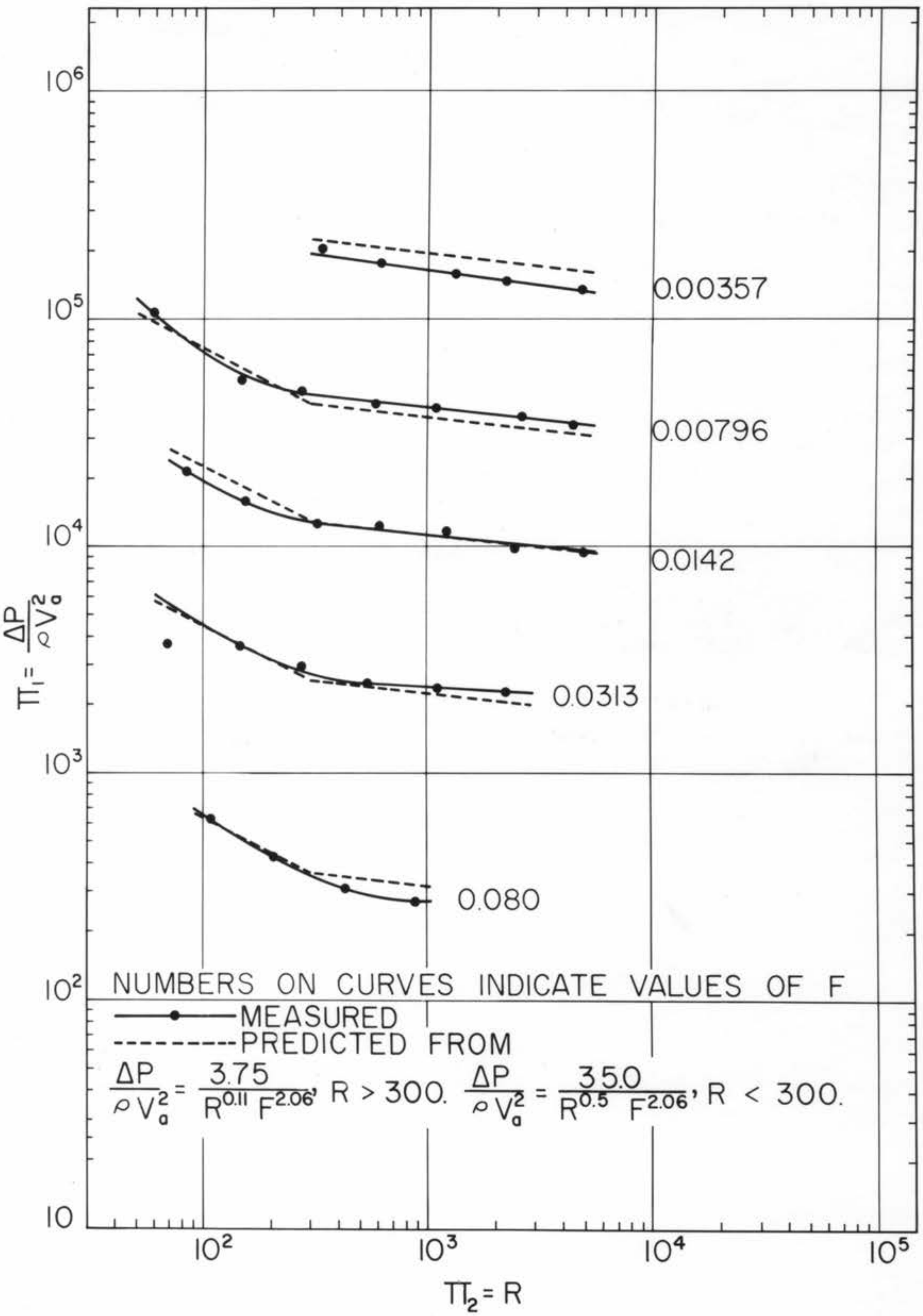
(Soybeans supported on perforated sheets having 3/32-in. diameter holes.)



$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$10^2$
$10^3$
$10^4$
$10^5$
$\Pi_1 = \frac{\Delta P}{\rho V_a^2}$
$\Pi_2 = R$
0.00357
0.00796
0.0142
0.0313
0.080
NUMBERS ON CURVES INDICATE VALUES OF F
MEASURED
PREDICTED FROM
$\frac{\Delta P}{\rho V_a^2} = \frac{1.40}{F^2}$, R >300.
$\frac{\Delta P}{\rho V_a^2} = \frac{24.23}{R^{0.5} F^2}$, R<300.

Figure 20. Relationship between Euler number and Reynolds number for Test 10

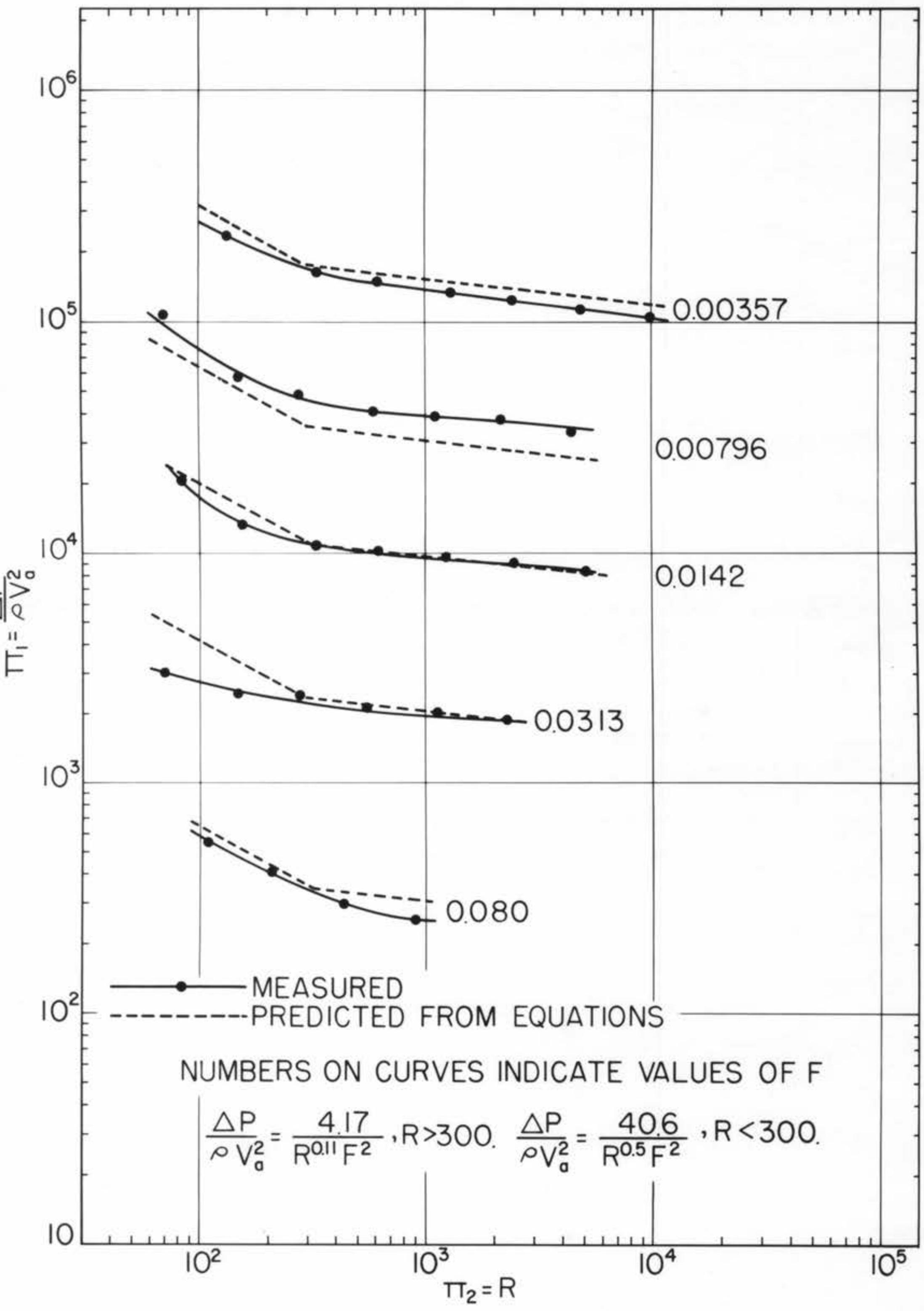
(Grain sorghum supported on perforated sheets having 3/32-in. diameter holes.)



$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$10^2$
$10^3$
$10^4$
$10^5$
$\Pi_1 = \frac{\Delta P}{\rho V_a^2}$
$\Pi_2 = R$
0.00357
0.00796
0.0142
0.0313
0.080
NUMBERS ON CURVES INDICATE VALUES OF F
MEASURED
PREDICTED FROM
$\frac{\Delta P}{\rho V_a^2} = \frac{3.75}{R^{0.11} F^{2.06}}$, R > 300. $\frac{\Delta P}{\rho V_a^2} = \frac{35.0}{R^{0.5} F^{2.06}}$, R < 300.

Figure 21. Relationship between Euler number and Reynolds number for Test 11

(Rice supported on perforated sheets having 3/32-in. diameter holes.)



$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
10
$10^2$
$10^3$
$10^4$
$10^5$
$\pi_1 = \frac{\Delta P}{\rho V_a^2}$
$\pi_2 = R$
0.00357
0.00796
0.0142
0.0313
0.080
MEASURED
PREDICTED FROM EQUATIONS
NUMBERS ON CURVES INDICATE VALUES OF F
$\frac{\Delta P}{\rho V_a^2} = \frac{4.17}{R^{0.11} F^2}$, R>300. $\frac{\Delta P}{\rho V_a^2} = \frac{40.6}{R^{0.5} F^2}$, R<300.

as the perforation diameter is increased. The extent of the increase depends on the grain, the value of F and the apparent velocity selected for the comparison. Comparing the apparent static pressure drop for wheat on the two sheet series at an apparent velocity of 0.2 ft/sec and F value of 0.02 yields the following result:

| Perforation diameter (in.) | $V_a$ ft/sec | F | $\Delta P$ lb/ft$^2$ | R |
|---|---|---|---|---|
| 3/32 | 0.2 | 0.02 | 0.663 | 451 |
| 3/16 | 0.2 | 0.02 | 1.086 | 902 |

$$\text{Predicted increase} = \frac{1.086 - 0.663}{0.663} \times 100 = 63.8 \text{ percent}$$

It is reasoned that part of the increase in apparent static pressure drop may be attributed to the reduction of the t/d ratio, the influence of which has been shown to be small. The remainder may be caused by an increase in the depth of the bed of grain in which flow is non-linear.

Tests 1 through 6 were conducted using a suction system. However, it was evident from the results of tests performed with sheets having a single perforation that changing from a suction to a pressure system might result in a reduction in the apparent static pressure drop through the perforated sheet. To further evaluate this influence the apparent static pressure drop through three of the perforated sheets used in conducting Tests 7 through 11 was obtained for both a suction and pressure system. A summary of the results is shown in Table 12 which was compiled from Appendix C. Apparently changing from a suction to a pressure system results in a reduction in the pressure drop across the perforated sheet when it is supporting grain.

Table 12. Average apparent static pressure reduction when the system is changed from suction to pressure

| Sheet no. | Grain | Pressure reduction (%) |
|---|---|---|
| A7 | Corn | 21 |
| A10 | " | 23 |
| A12 | " | 20 |
| A7 | Wheat | 24 |
| A10 | " | 24 |
| A12 | " | 20 |
| A7 | Soybeans | 17 |
| A10 | " | 25 |
| A12 | " | 19 |
| A7 | Sorghum | 23 |
| A10 | " | 26 |
| A12 | " | 25 |
| A7 | Rice | 25 |
| A10 | " | 24 |
| A12 | " | 23 |

## APPLICATION OF RESULTS

An equation of the form $\Delta P/\rho V_a^2 = C/R^n F^k$ may be used to compute the open area of a ventilating duct wall after values of C, n and k have been assumed or determined experimentally, and values of air density and viscosity are known. Auxiliary information is available to compute both the static pressure gradient along the duct and the radial air flow resistance of grain.

Shove (16) has presented an equation to evaluate the static pressure in a uniform duct at any point along its length. Hukill and Ives (7) have analyzed the radial air flow resistance of grain and Shedd (14) has provided data on the resistance of grain to air flow.

### Example

Compute the static pressure gradient and determine the required open area of a ventilating duct wall to provide uniform ventilation in a half cylindrical grain bin. The ventilating duct is to be installed along the center line of a corn storage building.

Length of building 100 ft

Width of building 22 ft

Radial depth of shelled corn 10 ft

Radius of ventilating duct 1 ft

Length of ventilating duct 100 ft

Ventilating rate 1/10 cfm per bushel

Fan on suction

The bin capacity is estimated at 15,200 bushels. For a ventilation rate of 1/10 cfm per bushel, the air flow through a half cylindrical duct wall is 15.2 cfm per ft of duct, or 4.82 cfm per $ft^2$ of duct wall.

Equation 6 in Hukill and Ives (7) article shows that a static pressure of 0.055 in. of water is required to move air from a 1 ft radius to an 11 ft radius through corn at a rate of 15.2 cfm per ft of duct. The pressure at the dead end of the duct must be -0.055 in. of water. Since the pressure increases negatively towards the fan, air must be throttled through the duct wall if uniform ventilation is to occur. The required variation in the restriction created by the duct wall will equal the difference between the duct pressure and that required to move air through the radial depth of grain at the prescribed rate.

The static pressure along the length of the duct may be predicted from the integrated form of Shove's (16) equation.

$$h - h_o = (V'_d/4000)^2 \, (-1.7 - \delta x/3D) \qquad (2)$$

where

$V'_d$ = air velocity in the duct, ft/min

$h$ = static pressure, in. of water

$h_o$ = static pressure, in. of water at the dead end

$x$ = length of duct from the dead end, ft

$D$ = hydraulic diameter, ft. (For noncircular ducts the hydraulic diameter is equal to four times the cross-sectional area divided by the wetted perimeter of the section. For this example the hydraulic diameter is 1.22 ft.)

$\delta$ = friction factor, 0.05 (16)

The value $h - h_o$ is the excess static pressure in the duct which must be dissipated in drawing air through the duct wall if uniform ventilation is to be obtained. The excess static pressure $h - h_o$ in in. of water was multiplied by a factor of 5.2 to convert it to $lb/ft^2$.

A summary of the calculations is contained in Table 13 where the figures in the column headed h are the predicted static pressures at the distance x from the dead end. The values of x selected represent the center of 10-ft sections of duct. The percentage open area for each 10-ft section will be selected on the basis of the pressure to be dissipated at the center of the section.

Selecting 16-gage perforated sheet metal having 3/32-in.-diameter holes punched on a staggered pattern, the required open area of the perforated sheets may be computed with the aid of Equation 20 and data from Table 9.

The expressions used are:

$$\Delta P = 4.39 \times 10^{-3} (V_a/F)^{1.93} \quad R > 300 \qquad (21)$$

or

$$\Delta P = 9.84 \times 10^{-3} (V_a/F)^{1.50} \quad R < 300 \qquad (22)$$

Proceeding with the computations, Equation 21 was used; however, on calculating the value of R at the 5, 15, 25, 35 and 45 ft locations, Reynolds number was found to be less than 300. The open area at these locations was recomputed using Equation 22. A summary of the

Table 13. Summary of calculations for the static pressure within the duct

| x | $V'_d$ | $(V'_d/4000)^2$ | $\delta x/3D$ | $(-1.7 - \delta x/3D)$ | $h-h_o$ | h |
|---|---|---|---|---|---|---|
| ft | ft/min | | | | in. of water | in. of water |
| 5 | 48.4 | $0.0146 \times 10^{-2}$ | 0.0682 | -1.7682 | -0.000 | -0.055 |
| 15 | 145.2 | 0.1318 " | 0.2047 | -1.9047 | -0.002 | -0.057 |
| 25 | 242.0 | 0.3660 " | 0.3412 | -2.0412 | -0.007 | -0.062 |
| 35 | 338.8 | 0.7174 " | 0.4778 | -2.1778 | -0.016 | -0.071 |
| 45 | 435.6 | 1.1859 " | 0.6142 | -2.3142 | -0.028 | -0.083 |
| 55 | 532.4 | 1.7716 " | 0.7508 | -2.4508 | -0.043 | -0.098 |
| 65 | 629.2 | 2.4740 " | 0.8817 | -2.5817 | -0.064 | -0.119 |
| 75 | 726.0 | 3.2942 " | 1.0240 | -2.7240 | -0.090 | -0.145 |
| 85 | 822.8 | 4.2312 " | 1.1600 | -2.8600 | -0.121 | -0.176 |
| 95 | 919.6 | 5.2854 " | 1.2970 | -2.9970 | -0.158 | -0.213 |
| 100 | 968.0 | 5.8564 " | 1.3650 | -3.0650 | -0.180 | -0.235 |

calculations and open area required in the duct wall is given in Tables 13, 14 and 15.

As the dead end of the duct is approached, the open area increases without limit since restriction of air is not required. Using Equation 22 and assuming an open area of 15 percent, the calculated apparent static pressure drop through the perforated sheet was $9.3 \times 10^{-4}$ in. of water. A Reynolds number of 24 was calculated for the above condition, whereas none of the tests conducted included Reynolds numbers in the range below approximately 45. However, it is believed that the error involved by this extrapolation is insignificant, since the pressure drop in this region for practical purposes is negligible.

Table 14. Required percentage of open area of the duct wall where Reynolds number is less than 300

| x<br>ft | $\Delta P$<br>$lb/ft^2$ | $\left(\frac{9.84x10^{-3}}{-\Delta P}\right)^{0.666}$ | $V_a\left(\frac{9.84x10^{-3}}{-\Delta P}\right)^{0.666}$ | Percent open area | Reynolds number |
|---|---|---|---|---|---|
| 5 | -0.0000 | $\infty$ | $\infty$ | $\infty$ | |
| 15 | -0.0104 | 0.963 | 0.0775 | 7.75 | 46.7 |
| 25 | -0.0364 | 0.418 | 0.0338 | 3.38 | 108.0 |
| 35 | -0.0830 | 0.240 | 0.0193 | 1.93 | 188.0 |
| 45 | -0.1452 | 0.166 | 0.0134 | 1.34 | 272.0 |

Table 15. Required percentage of open area of the duct wall where Reynolds number is greater than 300

| x<br>ft | $\Delta P$<br>$lb/ft^2$ | $\left(\frac{4.39x10^{-3}}{-\Delta P}\right)^{0.518}$ | $V_a\left(\frac{4.39x10^{-3}}{-\Delta P}\right)^{0.518}$ | Percent open area | Reynolds number |
|---|---|---|---|---|---|
| 55 | -0.224 | 0.01950 | 0.0105 | 1.05 | 347 |
| 65 | -0.333 | 0.01315 | 0.0086 | 0.86 | 426 |
| 75 | -0.467 | 0.00940 | 0.0072 | 0.72 | 506 |
| 85 | -0.628 | 0.00698 | 0.0061 | 0.61 | 595 |
| 95 | -0.820 | 0.00535 | 0.0053 | 0.53 | 685 |

## SUMMARY AND CONCLUSIONS

The object of this study was to establish the relationship among the variables influencing the apparent static pressure drop through a specific type of perforated sheet metal when supporting a particular grain.

Perforated sheets having round holes punched on an equilateral triangle pitch were selected for this study. The variables considered to influence the apparent static pressure drop were: fluid velocity, perforation diameter, center-to-center distance or pitch, sheet thickness, fluid density and viscosity, and the type and condition of the grain supported by the sheet. The variables were related by the functional form,

$$\Delta P = f(V, d, P, t, \rho, \mu, G) \tag{6}$$

Since three independent dimensions are involved, the variables were combined into five Pi terms and the following function written:

$$\Delta P/\rho V^2 = f(\rho V d/\mu,\ P/d,\ t/d,\ G) \tag{7}$$

Equation 7 was then rearranged and written

$$\Delta P/\rho V_a{}^2 = f(R, F, t/d, G). \tag{9}$$

The Pi term G, called the grain influence factor, was assumed to be dependent on such variables as the physical size and shape of the grain kernels or seeds, moisture content, amount of foreign material and mechanical damage present and the size and shape of the perforation. Throughout the test, G was assumed constant for each combination of grain and series of perforated sheets. Tests were conducted to evaluate the influence of the remaining independent Pi terms on $\Delta P/\rho V_a^2$.

Two series of sheets were used, one had 3/32-in.-diameter perforations and the other contained 3/16-in.-diameter holes. Both series had the perforations punched in 16-gauge steel stock on an equilateral triangle pitch. Relationships having the form

$$\Delta P/\rho V_a^2 = C/R^n F^k \tag{17}$$

were developed for the A and B sheet series with no grain covering the sheet and with the sheets supporting corn and wheat.

Auxiliary tests were conducted to evaluate the influence of the t/d ratio and the effect of changing from a suction to a pressure system. Additional tests were made with the sheet series having 3/32-in.-diameter perforations and relationships similar to that for corn and wheat developed for soybeans, grain sorghum and rice.

An example of the application of this information to the design of ducts for flat storages was given.

From this study of the air flow through perforated sheets supporting grain, the following conclusions have been reached.

1. When air is forced through a bed of grain supported by a perforated metal sheet, variations in the order of 2:1 may occur in the apparent static pressure drop through individual perforations.

2. Considering the grain influence factor and the ratio of t/d constant, the apparent static pressure drop through perforated sheet metal supporting grain may be related to Reynolds number and F by an expression of the following form:

$$\Delta P/\rho V_a^{\ 2} = C/R^n F^k$$

3. As the t/d ratio increases from 0.2 to 0.7, the apparent static pressure drop through perforated sheet metal supporting grain decreases slightly. The exact relationship was not determined.

4. The apparent static pressure drop through perforated sheets supporting grain is reduced when the system is changed from suction to pressure.

## SUGGESTED FUTURE STUDIES

Suggested areas for future study are:

1. Investigations to determine the influence that moisture content, amount of foreign material and mechanical damage have on the apparent static pressure drop through perforated sheets supporting grain.
2. Studies to determine the apparent static pressure drop through sheets having other types of openings, in particular those having indented and stabbed perforations.
3. Establish what relationship the thickness to diameter ratio has on the apparent static pressure drop.
4. Investigations to determine the apparent static pressure drop through perforated sheets when relative motion occurs between the sheet and grain. In certain grain drying installations, grain is recirculated through the dryer. This may result in grain moving slowly past the perforated dryer walls and floor.

## BIBLIOGRAPHY

1. American Society of Mechanical Engineers. Power Test Code, Part 5. Instruments and apparatus. Measurement of quality of materials. Chapter 4, Flow Measurements. New York, N. Y. author [c1959].

2. Bunn, J. M. Two-dimensional flow through porous media. Unpublished Ph.D. Thesis. Ames, Iowa. Library, Iowa State University of Science and Technology. 1960.

3. Foster, G. H. and Stahl, B. M. Operating grain aeration systems in the corn belt. U. S. Dept. of Agri., Agricultural Marketing Service, Marketing Research Division. Report 337. 1959.

4. Henderson, S. M. Resistance of shelled corn and bin walls to air flow. Agri. Eng. 24:367-394. 1943.

5. ________. Resistance of soybeans and oats to air flow. Agri. Eng. 25:125-128. 1944.

6. Holman, L. E., comp. Aeration of grain in commercial storages. U. S. Dept. of Agri., Agricultural Marketing Service, Marketing Research Division. Report 178. 1957.

7. Hukill, W. V. and Ives, N. C. Radial air flow resistance of grain. Agri. Eng. 36:332-335. 1955.

8. Kelly, C. F. Methods of ventilating wheat in farm storages. U. S. Dept. of Agri., Bureau of Agricultural Chemistry and Engineering, Division of Farm Structures Research. Circular 544. 1940.

9. Kolodzie, P. A. and Van Winkle, M. Discharge coefficients through perforated plates. Am. Inst. Chem. Eng. 3:305-312. 1957.

10. Murphy, Glenn. Similitude in engineering, N. Y., The Ronald Press Co. 1950.

11. Ringle, Henry. Stran-Steel Air-Meter, a product of conducting research on grain ventilation. Stran-Steel Farm Structures Research Conference, 1957:142-150. Detroit, Mich. Stran-Steel Corporation. 1950.

12. Robinson, R. N., Hukill, W. V., and Foster, G. H. Mechanical ventilation of stored grain. Agri. Eng. 32:606-608. 1951.

13. Rose, H. E. An investigation into the laws of flow of fluids through beds of granular materials. Inst. Mech. Eng. Proc. 153:141-153. 1945.

14. Shedd, C. K. Resistance of grains and seeds to air flow. Agri. Eng. 34:616-619. 1953.

15. ________. Some new data on resistance of grain to air flow. Agri. Eng. 32:493-495, 520. 1951.

16. Shove, G. C. Air flow analysis of grain ventilating ducts. Unpublished Ph.D. Thesis. Ames, Iowa. Library, Iowa State University of Science and Technology. 1959.

17. Smith, P. L., and Van Winkle, M. Discharge coefficients through perforated plates at Reynolds numbers of 400 to 3000. Am. Inst. Chem. Eng. 4:266-268. 1958.

18. Snedecor, G. W. Statistical methods. 5th ed. Ames, Iowa. The Iowa State College Press. 1956.

19. U. S. Dept. of Agri., Agricultural Engineering Research Division, Agricultural Research Service. Drying shelled corn with unheated air. Leaflet 332. 1952.

20. U. S. Dept. of Agri., Agricultural Marketing Service, Grain Division. Official grain standards of the U. S. Washington, D. C. U. S. Govt. Print. Off. 1957.

## ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to Professor William V. Hukill for guidance and counsel given during this study.

Appreciation is also expressed to Mr. Tappan Collins for his encouragement, to Mr. Robert A. Saul for assistance in obtaining and grading samples of grain, and to the Stran-Steel Corporation for their financial assistance.

Gratitude is expressed to Professor Hobart Beresford, Head, and to other members of the staff of the Department of Agricultural Engineering for use of facilities and many helpful suggestions.

## APPENDIX A: ORIGINAL AND CALCULATED DATA FOR TESTS 1 THROUGH 11

The tables contained in Appendix A were compiled from the values of the apparent static pressure drop obtained by the method outlined in the section on experimental procedure. The results of calculations for the coefficient of variation, Euler number and Reynolds number are also included. A sample of the computations follows.

Test number 3

Sheet number A12

Run number 4

$$\overline{X} = \Sigma X/n = \frac{0.492 + 0.411 + 0.476 + 0.468 + 0.526 + 0.570}{6}$$

| | | |
|---|---|---|
| $= 2.943/6$ | $=$ | $0.4905$ |
| $\Sigma X^2$ | $=$ | $1.45816$ |
| $\overline{X}\Sigma X$ | $=$ | $1.44354$ |
| $\Sigma X^2 - \overline{X}\Sigma X$ | $=$ | $0.01462$ |
| Standard deviation | $=$ | $0.0540$ |
| Coefficient of variation | $=$ | $(0.0540 \times 100)/0.4905$ |
| | $=$ | 11% |
| Apparent velocity for run 4 (Table 6) | $=$ | 6.206 ft/min |
| | $=$ | 0.1034 ft/sec |
| $\Delta P = 0.4509 \times 5.2$ | $=$ | 2.55 lb/ft$^2$ |

$\rho = 2.2 \times 10^{-3}$ slugs/ft$^3$

$\mu = 3.82 \times 10^{-7}$ lb sec/ft$^2$

Euler number

$$\Delta P/\rho V_a^{\,2} = \frac{2.55}{(2.2 \times 10^{-3})(0.1034)^2} \qquad = 1.08 \times 10^5$$

Reynolds number

$V_a$

$$R = \rho Vd/12\mu = \left(\frac{2.2 \times 10^{-3}}{3.82 \times 10^{-7}}\right)\left(\frac{0.1034}{0.00357}\right)\left(\frac{0.09375}{12}\right) \qquad = 1.31 \times 10^3$$

$F$

Table 16. Original and calculated data for Test 1

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Apparent pressure drop in. of water | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|
| A4 | 0.124 | 1 | | | | |
| | | 2 | | | | |
| | | 3 | | | | |
| | | 4 | | | | |
| | | 5 | | | | |
| | | 6 | 0.3806 | 138 | 0.005 | 81 |
| | | 7 | 0.7798 | 284 | 0.014 | 54 |
| | | 8 | 1.5855 | 575 | 0.052 | 49 |
| A5 | 0.080 | 1 | | | | |
| | | 2 | | | | |
| | | 3 | | | | |
| | | 4 | | | | |
| | | 5 | 0.1934 | 109 | 0.005 | 314 |
| | | 6 | 0.3806 | 215 | 0.012 | 195 |
| | | 7 | 0.7798 | 440 | 0.038 | 147 |
| | | 8 | 1.5855 | 894 | 0.140 | 131 |
| A6 | 0.0553 | 1 | | | | |
| | | 2 | | | | |
| | | 3 | | | | |
| | | 4 | 0.1034 | 84 | 0.002 | 437 |
| | | 5 | 0.1934 | 158 | 0.005 | 315 |
| | | 6 | 0.3806 | 310 | 0.017 | 277 |
| | | 7 | 0.7798 | 636 | 0.065 | 252 |
| | | 8 | 1.5855 | 1,290 | 0.271 | 253 |
| A7 | 0.0313 | 1 | | | | |
| | | 2 | | | | |
| | | 3 | | | | |
| | | 4 | 0.1034 | 149 | 0.005 | 1,104 |
| | | 5 | 0.1934 | 279 | 0.015 | 943 |
| | | 6 | 0.3806 | 549 | 0.054 | 880 |
| | | 7 | 0.7798 | 1,120 | 0.220 | 853 |
| | | 8 | 1.5855 | 2,280 | 1.000 | 935 |

Table 16. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Apparent pressure drop in. of water | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|
| A8 | 0.0206 | 1 | | | | |
| | | 2 | | | | |
| | | 3 | 0.0484 | 106 | 0.003 | 3,021 |
| | | 4 | 0.1034 | 226 | 0.012 | 2,650 |
| | | 5 | 0.1934 | 424 | 0.036 | 2,260 |
| | | 6 | 0.3806 | 834 | 0.125 | 2,040 |
| | | 7 | 0.7798 | 1,710 | 0.556 | 2,160 |
| | | 8 | 1.5855 | 3,470 | 2.478 | 2,316 |
| A9 | 0.0142 | 1 | | | | |
| | | 2 | 0.0264 | 84 | 0.003 | 10,100 |
| | | 3 | 0.0484 | 154 | 0.006 | 6,040 |
| | | 4 | 0.1034 | 328 | 0.021 | 4,640 |
| | | 5 | 0.1934 | 614 | 0.065 | 4,080 |
| | | 6 | 0.3806 | 1,210 | 0.252 | 4,100 |
| | | 7 | 0.7798 | 2,480 | 1.19 | 4,610 |
| | | 8 | 1.5855 | 5,040 | 5.07 | 4,740 |
| A10 | 0.00796 | 1 | 0.0105 | 59 | 0.0025 | 53,400 |
| | | 2 | 0.0264 | 150 | 0.006 | 20,300 |
| | | 3 | 0.0484 | 274 | 0.013 | 13,100 |
| | | 4 | 0.1034 | 586 | 0.063 | 13,900 |
| | | 5 | 0.1934 | 1,100 | 0.220 | 13,800 |
| | | 6 | 0.3806 | 2,160 | 0.970 | 15,800 |
| | | 7 | 0.7798 | 4,420 | 3.84 | 14,900 |
| | | 8 | 1.300 | 7,320 | 9.27 | 13,000 |
| A11 | 0.00495 | 1 | 0.0105 | 96 | 0.007 | 150,000 |
| | | 2 | 0.0264 | 241 | 0.016 | 54,000 |
| | | 3 | 0.0484 | 441 | 0.037 | 37,300 |
| | | 4 | 0.1034 | 942 | 0.155 | 34,200 |
| | | 5 | 0.1934 | 1,760 | 0.586 | 37,000 |
| | | 6 | 0.3806 | 3,470 | 2.52 | 41,000 |
| | | 7 | 0.7798 | 7,110 | 9.19 | 35,600 |
| | | 8 | 1.5855 | 14,400 | 34.23 | 32,000 |

Table 16. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Apparent pressure drop in. of water | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|
| A12 | 0.00357 | 1 | 0.0105 | 132 | 0.008 | 171,000 |
| | | 2 | 0.0264 | 334 | 0.023 | 77,700 |
| | | 3 | 0.0484 | 612 | 0.064 | 64,500 |
| | | 4 | 0.1034 | 1,310 | 0.275 | 60,700 |
| | | 5 | 0.1934 | 2,440 | 1.02 | 64,200 |
| | | 6 | 0.3806 | 4,810 | 4.28 | 69,700 |
| | | 7 | 0.7798 | 9,860 | 16.48 | 63,800 |
| | | 8 | | | | |
| A13 | 0.00206 | 1 | 0.0105 | 230 | 0.020 | 427,000 |
| | | 2 | 0.0264 | 578 | 0.063 | 214,000 |
| | | 3 | 0.0484 | 1,060 | 0.194 | 195,000 |
| | | 4 | 0.1034 | 2,260 | 0.970 | 214,000 |
| | | 5 | 0.1934 | 4,240 | 3.42 | 215,000 |
| | | 6 | 0.3806 | 8,340 | 11.28 | 184,000 |
| | | 7 | 0.7340 | 16,000 | 42.28 | 164,000 |
| | | 8 | | | | |
| A14 | 0.00127 | 1 | 0.0105 | 372 | 0.030 | 641,000 |
| | | 2 | 0.0264 | 938 | 0.155 | 524,000 |
| | | 3 | 0.0484 | 1,720 | 0.538 | 542,000 |
| | | 4 | 0.1034 | 3,670 | 2.735 | 604,000 |
| | | 5 | 0.1934 | 6,870 | 8.58 | 540,000 |
| | | 6 | 0.3806 | 9,600 | 32.10 | 523,000 |
| | | 7 | | | | |
| | | 8 | | | | |

Table 17. Original and calculated data for Test 2

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Apparent pressure drop in. of water | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|
| B3 | 0.173 | 1 | | | | |
| | | 2 | | | | |
| | | 3 | | | | |
| | | 4 | | | | |
| | | 5 | 0.1934 | 102 | 0.0005 | 36 |
| | | 6 | 0.3806 | 200 | 0.002 | 33 |
| | | 7 | 0.7798 | 410 | 0.007 | 27 |
| | | 8 | 1.5855 | 833 | 0.029 | 27 |
| B4 | 0.110 | 1 | | | | |
| | | 2 | | | | |
| | | 3 | | | | |
| | | 4 | | | | |
| | | 5 | 0.1934 | 160 | 0.002 | 126 |
| | | 6 | 0.3806 | 315 | 0.005 | 81 |
| | | 7 | 0.7798 | 645 | 0.018 | 70 |
| | | 8 | 1.5855 | 1,310 | 0.077 | 72 |
| B5 | 0.0828 | 1 | | | | |
| | | 2 | | | | |
| | | 3 | | | | |
| | | 4 | 0.1034 | 114 | 0.001 | 221 |
| | | 5 | 0.1934 | 210 | 0.002 | 126 |
| | | 6 | 0.3806 | 418 | 0.008 | 130 |
| | | 7 | 0.7798 | 856 | 0.033 | 128 |
| | | 8 | 1.5855 | 1,740 | 0.139 | 130 |
| B6 | 0.0423 | 1 | | | | |
| | | 2 | | | | |
| | | 3 | | | | |
| | | 4 | 0.1034 | 222 | 0.003 | 662 |
| | | 5 | 0.1934 | 416 | 0.008 | 503 |
| | | 6 | 0.3806 | 819 | 0.032 | 521 |
| | | 7 | 0.7798 | 1,680 | 0.145 | 562 |
| | | 8 | 1.5855 | 3,410 | 0.640 | 598 |

Table 17. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Apparent pressure drop in. of water | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|
| B7 | 0.0269 | 1 | 0.0105 | 35 | 0.0006 | 12,800 |
| | | 2 | 0.0264 | 89 | 0.001 | 3,380 |
| | | 3 | 0.0484 | 164 | 0.002 | 2,010 |
| | | 4 | 0.1034 | 350 | 0.006 | 1,320 |
| | | 5 | 0.1934 | 654 | 0.021 | 1,320 |
| | | 6 | 0.3806 | 1,290 | 0.083 | 1,350 |
| | | 7 | 0.7798 | 1,264 | 0.380 | 1,470 |
| | | 8 | 1.5855 | 5,360 | 1.66 | 1,550 |
| B8 | 0.0203 | 1 | 0.0105 | 47 | 0.001 | 21,400 |
| | | 2 | 0.0264 | 118 | 0.002 | 6,780 |
| | | 3 | 0.0484 | 217 | 0.003 | 3,020 |
| | | 4 | 0.1034 | 463 | 0.010 | 2,210 |
| | | 5 | 0.1934 | 866 | 0.036 | 2,260 |
| | | 6 | 0.3806 | 1,700 | 0.148 | 2,410 |
| | | 7 | 0.7798 | 3,490 | 0.660 | 2,560 |
| | | 8 | 1.5855 | 7,100 | 2.80 | 2,620 |
| B9 | 0.0104 | 1 | 0.0105 | 92 | 0.0025 | 53,400 |
| | | 2 | 0.0264 | 231 | 0.0055 | 18,600 |
| | | 3 | 0.0484 | 423 | 0.010 | 10,100 |
| | | 4 | 0.1034 | 904 | 0.040 | 8,930 |
| | | 5 | 0.1934 | 1,690 | 0.149 | 9,370 |
| | | 6 | 0.3806 | 3,330 | 0.626 | 10,200 |
| | | 7 | 0.7798 | 6,820 | 2.73 | 10,600 |
| | | 8 | 1.5855 | 13,900 | 10.79 | 10,100 |
| B10 | 0.00714 | 1 | 0.0105 | 133 | 0.003 | 64,100 |
| | | 2 | 0.0264 | 336 | 0.009 | 30,400 |
| | | 3 | 0.0484 | 617 | 0.021 | 21,100 |
| | | 4 | 0.1034 | 1,320 | 0.089 | 19,600 |
| | | 5 | 0.1934 | 2,460 | 0.350 | 22,000 |
| | | 6 | 0.3806 | 4,846 | 1.431 | 23,300 |
| | | 7 | 0.7798 | 9,910 | 6.00 | 23,200 |
| | | 8 | 1.5855 | 14,300 | 23.35 | 21,800 |

Table 17. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Apparent pressure drop in. of water | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|
| B11 | 0.00510 | 1 | 0.0105 | 187 | 0.005 | 107,000 |
| | | 2 | 0.0264 | 471 | 0.013 | 43,900 |
| | | 3 | 0.0484 | 863 | 0.036 | 36,200 |
| | | 4 | 0.1034 | 1,840 | 0.184 | 40,600 |
| | | 5 | 0.1934 | 3,450 | 0.650 | 40,900 |
| | | 6 | 0.3906 | 6,780 | 2.61 | 42,500 |
| | | 7 | 0.7798 | 13,900 | 10.65 | 41,300 |
| | | 8 | | | | |
| B12 | 0.00261 | 1 | 0.0105 | 365 | 0.011 | 235,000 |
| | | 2 | 0.0264 | 920 | 0.056 | 189,000 |
| | | 3 | 0.0484 | 1,690 | 0.138 | 139,000 |
| | | 4 | 0.1034 | 3,600 | 0.676 | 149,000 |
| | | 5 | 0.1934 | 6,740 | 2.54 | 160,000 |
| | | 6 | 0.3806 | 13,300 | 9.95 | 162,000 |
| | | 7 | | | | |
| | | 8 | | | | |
| B13 | 0.00192 | 1 | 0.0105 | 496 | 0.022 | 470,000 |
| | | 2 | 0.0264 | 1,250 | 0.088 | 297,000 |
| | | 3 | 0.0484 | 2,290 | 0.302 | 304,000 |
| | | 4 | 0.1034 | 4,810 | 1.435 | 317,000 |
| | | 5 | 0.1934 | 9,160 | 5.05 | 318,000 |
| | | 6 | 0.3806 | 18,000 | 18.65 | 304,000 |
| | | 7 | | | | |
| | | 8 | | | | |

Table 18. Original and calculated data for Test 3

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| A4 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| | 5 | 0.002 | 0.003 | 0.004 | 0.002 | 0.001 | 0.004 | 0.0027 | 39 |
| | 6 | 0.010 | 0.007 | 0.011 | 0.004 | 0.007 | 0.009 | 0.0080 | 32 |
| | 7 | 0.023 | 0.020 | 0.039 | 0.017 | 0.024 | 0.031 | 0.0267 | 31 |
| | 8 | 0.085 | 0.079 | 0.135 | 0.064 | 0.091 | 0.107 | 0.0936 | 27 |
| A5 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.0020 | 18 |
| | 5 | 0.008 | 0.005 | 0.006 | 0.007 | 0.007 | 0.007 | 0.0067 | 15 |
| | 6 | 0.024 | 0.017 | 0.018 | 0.019 | 0.018 | 0.020 | 0.0193 | 12 |
| | 7 | 0.084 | 0.059 | 0.067 | 0.064 | 0.061 | 0.067 | 0.0670 | 13 |
| | 8 | 0.311 | 0.221 | 0.257 | 0.237 | 0.231 | 0.250 | 0.2512 | 11 |
| A6 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.001 | 0.0013 | 43 |
| | 4 | 0.004 | 0.002 | 0.003 | 0.006 | 0.005 | 0.003 | 0.0038 | 39 |
| | 5 | 0.011 | 0.007 | 0.010 | 0.012 | 0.011 | 0.009 | 0.0100 | 18 |
| | 6 | 0.031 | 0.030 | 0.033 | 0.030 | 0.040 | 0.033 | 0.0328 | 9 |
| | 7 | 0.100 | 0.110 | 0.130 | 0.140 | 0.150 | 0.113 | 0.1233 | 17 |
| | 8 | 0.48 | 0.47 | 0.46 | 0.48 | 0.53 | 0.44 | 0.477 | 9 |
| A7 | 1 | | | | | | | | |
| | 2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0010 | 0 |
| | 3 | 0.003 | 0.003 | 0.004 | 0.002 | 0.003 | 0.003 | 0.0030 | 14 |
| | 4 | 0.009 | 0.008 | 0.009 | 0.009 | 0.008 | 0.010 | 0.0088 | 9 |
| | 5 | 0.029 | 0.027 | 0.032 | 0.025 | 0.027 | 0.025 | 0.0275 | 9 |
| | 6 | 0.060 | 0.096 | 0.100 | 0.100 | 0.104 | 0.093 | 0.0922 | 17 |
| | 7 | 0.42 | 0.38 | 0.42 | 0.40 | 0.45 | 0.37 | 0.406 | 7 |
| | 8 | 1.58 | 1.50 | 1.60 | 1.56 | 1.66 | 1.53 | 1.572 | 4 |

*In. of water.

Table 18. (Continued)

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| A8 | 1 | | | | | | | | |
| | 2 | 0.002 | 0.002 | 0.003 | 0.002 | 0.003 | 0.003 | 0.0025 | 22 |
| | 3 | 0.006 | 0.006 | 0.007 | 0.006 | 0.007 | 0.006 | 0.0063 | 1 |
| | 4 | 0.016 | 0.017 | 0.019 | 0.017 | 0.020 | 0.018 | 0.0178 | 8 |
| | 5 | 0.055 | 0.060 | 0.059 | 0.059 | 0.064 | 0.059 | 0.0593 | 5 |
| | 6 | 0.216 | 0.223 | 0.221 | 0.226 | 0.245 | 0.216 | 0.2245 | 5 |
| | 7 | 0.89 | 0.90 | 0.82 | 0.94 | 1.00 | 0.94 | 0.915 | 7 |
| | 8 | 3.66 | 3.62 | 3.65 | 3.60 | 3.91 | 3.62 | 3.676 | 6 |
| A9 | 1 | | | | | | | | |
| | 2 | 0.003 | 0.004 | 0.004 | 0.003 | 0.004 | 0.004 | 0.0037 | 13 |
| | 3 | 0.009 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.0098 | 4 |
| | 4 | 0.035 | 0.035 | 0.042 | 0.034 | 0.034 | 0.035 | 0.0358 | 8 |
| | 5 | 0.122 | 0.127 | 0.133 | 0.118 | 0.125 | 0.129 | 0.1256 | 4 |
| | 6 | 0.47 | 0.47 | 0.50 | 0.47 | 0.47 | 0.48 | 0.477 | 3 |
| | 7 | 2.03 | 1.93 | 1.97 | 1.92 | 2.00 | 1.99 | 1.973 | 4 |
| | 8 | 7.19 | 7.57 | 7.66 | 7.40 | 7.60 | 7.69 | 7.518 | 2 |
| A10 | 1 | 0.006 | 0.003 | 0.006 | 0.004 | 0.005 | 0.004 | 0.0047 | 25 |
| | 2 | 0.013 | 0.013 | 0.014 | 0.011 | 0.011 | 0.011 | 0.0122 | 11 |
| | 3 | 0.031 | 0.027 | 0.035 | 0.030 | 0.027 | 0.028 | 0.0297 | 10 |
| | 4 | 0.117 | 0.114 | 0.141 | 0.114 | 0.112 | 0.120 | 0.1197 | 9 |
| | 5 | 0.428 | 0.402 | 0.513 | 0.421 | 0.405 | 0.436 | 0.4342 | 9 |
| | 6 | 1.62 | 1.51 | 1.94 | 1.58 | 1.58 | 1.69 | 1.653 | 9 |
| | 7 | 6.55 | 5.99 | 7.38 | 6.10 | 5.95 | 6.57 | 6.423 | 8 |
| | 8 | 25.05 | 23.50 | 28.17 | 22.85 | 22.84 | 23.57 | 24.33 | 8 |
| A11 | 1 | 0.007 | 0.010 | 0.007 | 0.008 | 0.008 | 0.010 | 0.0083 | 17 |
| | 2 | 0.024 | 0.028 | 0.036 | 0.025 | 0.026 | 0.026 | 0.0275 | 16 |
| | 3 | 0.068 | 0.070 | 0.083 | 0.074 | 0.069 | 0.067 | 0.0718 | 8 |
| | 4 | 0.302 | 0.349 | 0.319 | 0.317 | 0.306 | 0.297 | 0.3150 | 6 |
| | 5 | 1.14 | 1.28 | 1.24 | 1.26 | 1.25 | 1.19 | 1.227 | 4 |
| | 6 | 3.97 | 4.63 | 4.28 | 4.23 | 4.04 | 4.05 | 4.200 | 6 |
| | 7 | 15.24 | 17.29 | 16.10 | 16.14 | 15.68 | 15.17 | 15.937 | 5 |
| | 8 | | | | | | | | |

Table 18. (Continued)

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| A12 | 1 | 0.011 | 0.009 | 0.010 | 0.010 | 0.010 | 0.011 | 0.0101 | 8 |
| | 2 | 0.034 | 0.031 | 0.036 | 0.034 | 0.038 | 0.041 | 0.0357 | 10 |
| | 3 | 0.101 | 0.093 | 0.109 | 0.104 | 0.114 | 0.129 | 0.1083 | 11 |
| | 4 | 0.492 | 0.411 | 0.476 | 0.468 | 0.526 | 0.570 | 0.4905 | 11 |
| | 5 | 1.84 | 1.60 | 1.77 | 1.84 | 1.92 | 2.10 | 1.845 | 9 |
| | 6 | 6.38 | 5.80 | 6.33 | 6.47 | 6.65 | 7.30 | 6.488 | 8 |
| | 7 | 24.79 | 21.89 | 23.89 | 24.78 | 26.35 | 28.16 | 24.977 | 8 |
| | 8 | | | | | | | | |
| A13 | 1 | 0.027 | 0.033 | 0.035 | 0.022 | 0.027 | 0.027 | 0.0286 | 17 |
| | 2 | 0.099 | 0.162 | 0.134 | 0.101 | 0.096 | 0.127 | 0.1200 | 22 |
| | 3 | 0.324 | 0.510 | 0.405 | 0.329 | 0.297 | 0.417 | 0.3800 | 20 |
| | 4 | 1.48 | 2.11 | 1.73 | 1.46 | 1.34 | 1.79 | 1.652 | 32 |
| | 5 | 5.04 | 7.54 | 6.14 | 4.99 | 4.65 | 6.10 | 5.743 | 19 |
| | 6 | 17.55 | 27.20 | 21.40 | 17.71 | 16.06 | 22.01 | 20.322 | 20 |
| | 7 | | | | | | | | |
| | 8 | | | | | | | | |
| A14 | 1 | 0.101 | 0.086 | 0.037 | 0.044 | 0.079 | 0.043 | 0.0650 | 41 |
| | 2 | 0.372 | 0.303 | 0.188 | 0.186 | 0.401 | 0.211 | 0.2768 | 35 |
| | 3 | 1.169 | 0.958 | 0.638 | 0.631 | 1.293 | 0.673 | 0.8937 | 32 |
| | 4 | 4.73 | 3.95 | 2.83 | 2.38 | 4.99 | 3.03 | 3.652 | 29 |
| | 5 | 15.80 | 13.08 | 9.20 | 9.00 | 16.57 | 9.81 | 12.224 | 28 |
| | 6 | | | | | | | | |
| | 7 | | | | | | | | |
| | 8 | | | | | | | | |

Table 19. Calculated data for Test 3

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| A4 | 0.124 | 1 | | | |
| | | 2 | | | |
| | | 3 | | | |
| | | 4 | | | |
| | | 5 | 0.1934 | 70 | 170 |
| | | 6 | 0.3806 | 138 | 130 |
| | | 7 | 0.7798 | 284 | 101 |
| | | 8 | 1.5855 | 575 | 88 |
| A5 | 0.080 | 1 | | | |
| | | 2 | | | |
| | | 3 | | | |
| | | 4 | 0.1034 | 58 | 441 |
| | | 5 | 0.1934 | 109 | 421 |
| | | 6 | 0.3806 | 215 | 314 |
| | | 7 | 0.7798 | 440 | 260 |
| | | 8 | 1.5855 | 894 | 234 |
| A6 | 0.0553 | 1 | | | |
| | | 2 | | | |
| | | 3 | 0.0484 | 40 | 1,310 |
| | | 4 | 0.1034 | 84 | 839 |
| | | 5 | 0.1934 | 158 | 629 |
| | | 6 | 0.3806 | 310 | 456 |
| | | 7 | 0.7798 | 636 | 478 |
| | | 8 | 1.5855 | 1,290 | 446 |
| A7 | 0.0313 | 1 | | | |
| | | 2 | 0.0264 | 38 | 3,380 |
| | | 3 | 0.0484 | 70 | 3,020 |
| | | 4 | 0.1034 | 149 | 1,940 |
| | | 5 | 0.1934 | 279 | 1,730 |
| | | 6 | 0.3806 | 549 | 1,500 |
| | | 7 | 0.7798 | 1,120 | 1,570 |
| | | 8 | 1.5855 | 2,280 | 1,470 |

Table 19. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| A8 | 0.0206 | 1 | | | |
| | | 2 | 0.0264 | 58 | 8,450 |
| | | 3 | 0.0484 | 106 | 6,340 |
| | | 4 | 0.1034 | 226 | 3,930 |
| | | 5 | 0.1934 | 424 | 3,730 |
| | | 6 | 0.3806 | 834 | 3,660 |
| | | 7 | 0.7798 | 1,710 | 3,550 |
| | | 8 | 1.5855 | 3,470 | 3,440 |
| A9 | 0.0142 | 1 | | | |
| | | 2 | 0.0264 | 84 | 12,500 |
| | | 3 | 0.0484 | 154 | 9,870 |
| | | 4 | 0.1034 | 328 | 7,900 |
| | | 5 | 0.1934 | 614 | 7,900 |
| | | 6 | 0.3806 | 1,210 | 7,770 |
| | | 7 | 0.7798 | 2,480 | 7,650 |
| | | 8 | 1.5855 | 5,050 | 7,030 |
| A10 | 0.00796 | 1 | 0.0105 | 59 | 100,000 |
| | | 2 | 0.0264 | 150 | 41,200 |
| | | 3 | 0.0484 | 274 | 29,900 |
| | | 4 | 0.1034 | 586 | 26,400 |
| | | 5 | 0.1934 | 1,100 | 27,300 |
| | | 6 | 0.3806 | 2,161 | 26,900 |
| | | 7 | 0.7798 | 4,420 | 24,900 |
| | | 8 | 1.5855 | 8,990 | 22,700 |
| A11 | 0.00495 | 1 | 0.0105 | 96 | 177,000 |
| | | 2 | 0.0264 | 241 | 92,900 |
| | | 3 | 0.0484 | 441 | 72,300 |
| | | 4 | 0.1034 | 942 | 69,500 |
| | | 5 | 0.1934 | 1,760 | 77,200 |
| | | 6 | 0.3806 | 3,470 | 68,400 |
| | | 7 | 0.7798 | 7,110 | 61,800 |
| | | 8 | | | |

Table 19. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| A12 | 0.00357 | 1 | 0.0105 | 132 | 216,000 |
| | | 2 | 0.0264 | 334 | 121,000 |
| | | 3 | 0.0484 | 612 | 109,000 |
| | | 4 | 0.1034 | 1,310 | 108,000 |
| | | 5 | 0.1934 | 2,440 | 116,000 |
| | | 6 | 0.3806 | 4,810 | 106,000 |
| | | 7 | 0.7798 | 9,860 | 96,900 |
| | | 8 | | | |
| A13 | 0.00206 | 1 | 0.0105 | 230 | 611,000 |
| | | 2 | 0.0264 | 578 | 403,000 |
| | | 3 | 0.0484 | 1,060 | 383,000 |
| | | 4 | 0.1034 | 2,260 | 365,000 |
| | | 5 | 0.1934 | 4,240 | 361,000 |
| | | 6 | 0.3806 | 8,340 | 331,000 |
| | | 7 | | | |
| | | 8 | | | |
| A14 | 0.00127 | 1 | 0.0105 | 372 | 1,390,000 |
| | | 2 | 0.0264 | 938 | 935,000 |
| | | 3 | 0.0484 | 1,720 | 900,000 |
| | | 4 | 0.1034 | 3,670 | 806,000 |
| | | 5 | 0.1934 | 6,870 | 770,000 |
| | | 6 | | | |
| | | 7 | | | |
| | | 8 | | | |

Table 20. Original and calculated data for Test 4

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| B3 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| | 5 | 0.004 | 0.001 | 0.001 | 0.002 | 0.001 | 0.001 | 0.0017 | 66 |
| | 6 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.013 | 47 |
| | 7 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.023 | 56 |
| | 8 | 0.12 | 0.11 | 0.07 | 0.07 | 0.07 | 0.06 | 0.083 | 67 |
| B4 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| | 5 | 0.005 | 0.007 | 0.003 | 0.004 | 0.005 | 0.003 | 0.0045 | 33 |
| | 6 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 | 0.017 | 27 |
| | 7 | 0.04 | 0.07 | 0.06 | 0.06 | 0.06 | 0.06 | 0.058 | 17 |
| | 8 | 0.22 | 0.20 | 0.18 | 0.16 | 0.19 | 0.28 | 0.205 | 20 |
| B5 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.000 | 0.0010 | 63 |
| | 4 | 0.001 | 0.003 | 0.002 | 0.001 | 0.003 | 0.003 | 0.0022 | 46 |
| | 5 | 0.009 | 0.008 | 0.009 | 0.010 | 0.009 | 0.012 | 0.0095 | 14 |
| | 6 | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.033 | 13 |
| | 7 | 0.10 | 0.12 | 0.09 | 0.08 | 0.11 | 0.08 | 0.097 | 17 |
| | 8 | 0.37 | 0.42 | 0.35 | 0.37 | 0.37 | 0.44 | 0.387 | 9 |
| B6 | 1 | | | | | | | | |
| | 2 | 0.000 | 0.001 | 0.002 | 0.001 | 0.001 | 0.001 | 0.0010 | 63 |
| | 3 | 0.003 | 0.004 | 0.003 | 0.003 | 0.002 | 0.003 | 0.0030 | 21 |
| | 4 | 0.008 | 0.010 | 0.009 | 0.012 | 0.008 | 0.011 | 0.0097 | 17 |
| | 5 | 0.031 | 0.033 | 0.035 | 0.031 | 0.029 | 0.035 | 0.0323 | 8 |
| | 6 | 0.11 | 0.12 | 0.13 | 0.13 | 0.10 | 0.118 | 0.118 | 10 |
| | 7 | 0.42 | 0.45 | 0.47 | 0.47 | 0.41 | 0.48 | 0.450 | 6 |
| | 8 | 1.50 | 1.64 | 1.77 | 1.77 | 1.52 | 1.70 | 1.650 | 7 |

*In. of water.

Table 20. (Continued)

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| B7 | 1 | 0.001 | 0.002 | 0.001 | 0.002 | 0.001 | 0.001 | 0.0013 | 35 |
| | 2 | 0.003 | 0.003 | 0.003 | 0.004 | 0.003 | 0.002 | 0.0030 | 21 |
| | 3 | 0.006 | 0.007 | 0.007 | 0.008 | 0.007 | 0.007 | 0.0070 | 9 |
| | 4 | 0.024 | 0.012 | 0.024 | 0.028 | 0.022 | 0.022 | 0.0220 | 24 |
| | 5 | 0.078 | 0.073 | 0.082 | 0.099 | 0.082 | 0.076 | 0.0816 | 11 |
| | 6 | 0.29 | 0.26 | 0.29 | 0.36 | 0.29 | 0.27 | 0.293 | 12 |
| | 7 | 1.11 | 1.02 | 1.15 | 1.36 | 1.13 | 1.00 | 1.128 | 11 |
| | 8 | 4.21 | 3.05 | 4.31 | 4.29 | 4.35 | 4.00 | 4.035 | 12 |
| B8 | 1 | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.0018 | 27 |
| | 2 | 0.004 | 0.003 | 0.004 | 0.004 | 0.004 | 0.007 | 0.0043 | 33 |
| | 3 | 0.012 | 0.010 | 0.009 | 0.009 | 0.010 | 0.014 | 0.0107 | 17 |
| | 4 | 0.041 | 0.039 | 0.036 | 0.034 | 0.035 | 0.058 | 0.0405 | 22 |
| | 5 | 0.142 | 0.131 | 0.126 | 0.113 | 0.122 | 0.180 | 0.1357 | 17 |
| | 6 | 0.50 | 0.48 | 0.45 | 0.43 | 0.44 | 0.63 | 0.488 | 15 |
| | 7 | 1.91 | 1.94 | 1.89 | 1.69 | 1.69 | 2.28 | 1.900 | 11 |
| | 8 | 8.23 | 7.25 | 6.63 | 6.27 | 6.50 | 8.31 | 7.198 | 12 |
| B9 | 1 | 0.006 | 0.005 | 0.004 | 0.005 | 0.004 | 0.007 | 0.0051 | 23 |
| | 2 | 0.024 | 0.014 | 0.016 | 0.014 | 0.015 | 0.019 | 0.0170 | 23 |
| | 3 | 0.044 | 0.033 | 0.036 | 0.039 | 0.041 | 0.042 | 0.0392 | 10 |
| | 4 | 0.168 | 0.133 | 0.145 | 0.151 | 0.166 | 0.176 | 0.1565 | 10 |
| | 5 | 0.580 | 0.450 | 0.500 | 0.520 | 0.560 | 0.590 | 0.5333 | 10 |
| | 6 | 2.07 | 1.63 | 1.80 | 1.86 | 1.97 | 2.17 | 1.916 | 10 |
| | 7 | 7.97 | 6.40 | 7.11 | 7.25 | 7.97 | 8.73 | 7.571 | 11 |
| | 8 | 32.39 | 24.50 | 28.77 | 27.97 | 32.78 | 34.01 | 30.070 | 12 |
| B10 | 1 | 0.009 | 0.009 | 0.014 | 0.010 | 0.009 | 0.009 | 0.0100 | 20 |
| | 2 | 0.031 | 0.023 | 0.038 | 0.028 | 0.029 | 0.026 | 0.0292 | 18 |
| | 3 | 0.092 | 0.060 | 0.105 | 0.076 | 0.078 | 0.069 | 0.0800 | 20 |
| | 4 | 0.280 | 0.238 | 0.417 | 0.319 | 0.314 | 0.283 | 0.3085 | 20 |
| | 5 | 1.18 | 0.81 | 1.42 | 1.05 | 1.05 | 0.92 | 1.072 | 20 |
| | 6 | 4.27 | 2.95 | 5.03 | 3.82 | 3.81 | 3.37 | 3.875 | 19 |
| | 7 | 16.88 | 11.42 | 19.52 | 15.18 | 15.15 | 13.15 | 15.216 | 18 |
| | 8 | | | | | | | | |

Table 20. (Continued)

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| B11 | 1 | 0.013 | 0.011 | 0.012 | 0.014 | 0.009 | 0.015 | 0.0123 | 19 |
| | 2 | 0.052 | 0.047 | 0.055 | 0.057 | 0.040 | 0.061 | 0.0516 | 39 |
| | 3 | 0.156 | 0.135 | 0.166 | 0.166 | 0.120 | 0.189 | 0.1553 | 25 |
| | 4 | 0.652 | 0.582 | 0.702 | 0.692 | 0.668 | 0.780 | 0.6793 | 21 |
| | 5 | 2.13 | 1.88 | 2.35 | 2.25 | 1.71 | 2.60 | 2.153 | 34 |
| | 6 | 7.78 | 6.74 | 8.48 | 8.16 | 6.19 | 9.35 | 7.783 | 33 |
| | 7 | 30.45 | 25.99 | 33.69 | 31.77 | 24.36 | 35.52 | 30.298 | 10 |
| | 8 | | | | | | | | |
| B12 | 1 | 0.043 | 0.041 | 0.032 | 0.035 | 0.020 | 0.048 | 0.0365 | 27 |
| | 2 | 0.205 | 0.207 | 0.139 | 0.153 | 0.090 | 0.216 | 0.1683 | 30 |
| | 3 | 0.635 | 0.638 | 0.421 | 0.469 | 0.287 | 0.649 | 0.5165 | 29 |
| | 4 | 2.03 | 2.08 | 1.18 | 2.01 | 1.23 | 2.73 | 1.877 | 31 |
| | 5 | 9.06 | 9.26 | 6.10 | 6.85 | 4.25 | 9.16 | 7.446 | 28 |
| | 6 | 33.00 | 33.54 | 22.39 | 24.77 | 15.25 | 34.00 | 27.158 | 17 |
| | 7 | | | | | | | | |
| | 8 | | | | | | | | |
| B13 | 1 | 0.094 | 0.036 | 0.050 | 0.067 | 0.058 | 0.063 | 0.0613 | 32 |
| | 2 | 0.443 | 0.172 | 0.222 | 0.349 | 0.266 | 0.328 | 0.2967 | 31 |
| | 3 | 1.370 | 0.536 | 0.705 | 1.060 | 0.845 | 1.050 | 0.9277 | 32 |
| | 4 | 4.84 | 2.14 | 2.92 | 4.54 | 3.44 | 4.24 | 3.687 | 28 |
| | 5 | 16.61 | 7.36 | 10.01 | 15.16 | 12.30 | 14.46 | 12.650 | 28 |
| | 6 | | | | | | | | |
| | 7 | | | | | | | | |
| | 8 | | | | | | | | |

Table 21. Calculated data for Test 4

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| B3 | 0.173 | 1 | | | |
| | | 2 | | | |
| | | 3 | | | |
| | | 4 | | | |
| | | 5 | 0.1934 | 102 | 107 |
| | | 6 | 0.3806 | 200 | 212 |
| | | 7 | 0.7798 | 410 | 89 |
| | | 8 | 1.5855 | 833 | 78 |
| B4 | 0.110 | 1 | | | |
| | | 2 | | | |
| | | 3 | | | |
| | | 4 | | | |
| | | 5 | 0.1934 | 160 | 283 |
| | | 6 | 0.3806 | 315 | 277 |
| | | 7 | 0.7798 | 645 | 225 |
| | | 8 | 1.5855 | 1,310 | 192 |
| B5 | 0.0828 | 1 | | | |
| | | 2 | | | |
| | | 3 | 0.0484 | 54 | 1,010 |
| | | 4 | 0.1034 | 114 | 486 |
| | | 5 | 0.1934 | 212 | 597 |
| | | 6 | 0.3806 | 418 | 537 |
| | | 7 | 0.7798 | 856 | 376 |
| | | 8 | 1.5855 | 1,740 | 362 |
| B6 | 0.0423 | 1 | | | |
| | | 2 | 0.0264 | 57 | 3,370 |
| | | 3 | 0.0484 | 104 | 3,020 |
| | | 4 | 0.1034 | 222 | 2,140 |
| | | 5 | 0.1934 | 416 | 2,030 |
| | | 6 | 0.3806 | 819 | 1,920 |
| | | 7 | 0.7798 | 1,680 | 1,740 |
| | | 8 | 1.5855 | 3,410 | 1,540 |

Table 21. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| B7 | 0.0269 | 1 | 0.0105 | 35 | 27,800 |
| | | 2 | 0.0264 | 89 | 10,100 |
| | | 3 | 0.0484 | 164 | 7,050 |
| | | 4 | 0.1034 | 350 | 4,860 |
| | | 5 | 0.1934 | 654 | 5,130 |
| | | 6 | 0.3806 | 1,290 | 4,770 |
| | | 7 | 0.7798 | 2,640 | 4,370 |
| | | 8 | 1.5855 | 5,360 | 3,770 |
| B8 | 0.0203 | 1 | 0.0105 | 47 | 38,500 |
| | | 2 | 0.0264 | 118 | 14,500 |
| | | 3 | 0.0484 | 217 | 10,800 |
| | | 4 | 0.1034 | 463 | 8,940 |
| | | 5 | 0.1934 | 866 | 8,530 |
| | | 6 | 0.3806 | 1,700 | 7,950 |
| | | 7 | 0.7798 | 3,490 | 7,360 |
| | | 8 | 1.5855 | 7,100 | 6,730 |
| B9 | 0.0104 | 1 | 0.0105 | 91 | 109,000 |
| | | 2 | 0.0264 | 231 | 57,400 |
| | | 3 | 0.0484 | 423 | 39,500 |
| | | 4 | 0.1034 | 904 | 34,500 |
| | | 5 | 0.1934 | 1,690 | 33,500 |
| | | 6 | 0.3806 | 3,330 | 31,900 |
| | | 7 | 0.7798 | 6,820 | 29,300 |
| | | 8 | 1.5855 | 13,900 | 28,100 |
| B10 | 0.00714 | 1 | 0.0105 | 133 | 213,000 |
| | | 2 | 0.0264 | 336 | 98,600 |
| | | 3 | 0.0484 | 617 | 80,600 |
| | | 4 | 0.1034 | 1,320 | 68,100 |
| | | 5 | 0.1934 | 2,460 | 67,400 |
| | | 6 | 0.3806 | 4,846 | 63,100 |
| | | 7 | 0.7798 | 9,910 | 59,000 |
| | | 8 | | | |

Table 21. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| B11a | 0.00495 | 1 | 0.0105 | 187 | 263,000 |
| | | 2 | 0.0264 | 471 | 174,000 |
| | | 3 | 0.0484 | 863 | 156,000 |
| | | 4 | 0.1034 | 1,840 | 150,000 |
| | | 5 | 0.1934 | 3,450 | 135,000 |
| | | 6 | 0.3806 | 6,780 | 127,000 |
| | | 7 | 0.7798 | 13,900 | 117,000 |
| | | 8 | | | |
| B12 | 0.00261 | 1 | 0.0105 | 365 | 780,000 |
| | | 2 | 0.0264 | 920 | 569,000 |
| | | 3 | 0.0484 | 1,690 | 520,000 |
| | | 4 | 0.1034 | 3,600 | 414,000 |
| | | 5 | 0.1934 | 6,740 | 468,000 |
| | | 6 | 0.3806 | 13,300 | 442,000 |
| | | 7 | | | |
| | | 8 | | | |
| B13 | 0.00192 | 1 | 0.0105 | 496 | 1,310,000 |
| | | 2 | 0.0264 | 1,250 | 1,000,000 |
| | | 3 | 0.0484 | 2,290 | 934,000 |
| | | 4 | 0.1034 | 4,810 | 814,000 |
| | | 5 | 0.1934 | 9,160 | 796,000 |
| | | 6 | | | |
| | | 7 | | | |
| | | 8 | | | |

Table 22. Original and calculated data for Test 5

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| A4 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | 0.002 | 0.003 | 0.002 | 0.002 | 0.003 | 0.003 | 0.0025 | 22 |
| | 5 | 0.006 | 0.008 | 0.005 | 0.005 | 0.004 | 0.008 | 0.0060 | 29 |
| | 6 | 0.013 | 0.012 | 0.011 | 0.011 | 0.009 | 0.015 | 0.0118 | 17 |
| | 7 | 0.035 | 0.029 | 0.032 | 0.037 | 0.024 | 0.040 | 0.0328 | 17 |
| | 8 | 0.125 | 0.097 | 0.102 | 0.127 | 0.088 | 0.131 | 0.1117 | 16 |
| A5 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | 0.003 | 0.004 | 0.004 | 0.005 | 0.005 | 0.004 | 0.0042 | 17 |
| | 5 | 0.010 | 0.013 | 0.010 | 0.014 | 0.011 | 0.010 | 0.0113 | 14 |
| | 6 | 0.028 | 0.035 | 0.029 | 0.035 | 0.030 | 0.029 | 0.0310 | 10 |
| | 7 | 0.102 | 0.117 | 0.100 | 0.118 | 0.106 | 0.100 | 0.1072 | 8 |
| | 8 | 0.377 | 0.420 | 0.366 | 0.379 | 0.376 | 0.366 | 0.3807 | 5 |
| A6 | 1 | | | | | | | | |
| | 2 | 0.002 | 0.001 | 0.002 | 0.001 | 0.001 | 0.001 | 0.0013 | 34 |
| | 3 | 0.003 | 0.002 | 0.003 | 0.001 | 0.003 | 0.002 | 0.0023 | 39 |
| | 4 | 0.008 | 0.004 | 0.004 | 0.003 | 0.004 | 0.006 | 0.0049 | 37 |
| | 5 | 0.017 | 0.026 | 0.020 | 0.016 | 0.015 | 0.015 | 0.0182 | 24 |
| | 6 | 0.056 | 0.060 | 0.050 | 0.060 | 0.050 | 0.050 | 0.0543 | 9 |
| | 7 | 0.17 | 0.17 | 0.22 | 0.20 | 0.18 | 0.16 | 0.183 | 12 |
| | 8 | 0.77 | 0.70 | 0.70 | 0.75 | 0.70 | 0.68 | 0.717 | 5 |
| A7 | 1 | | | | | | | | |
| | 2 | 0.002 | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 | 0.0023 | 22 |
| | 3 | 0.007 | 0.006 | 0.006 | 0.005 | 0.004 | 0.006 | 0.0057 | 18 |
| | 4 | 0.018 | 0.010 | 0.018 | 0.014 | 0.015 | 0.012 | 0.0145 | 23 |
| | 5 | 0.052 | 0.045 | 0.050 | 0.050 | 0.045 | 0.052 | 0.0490 | 7 |
| | 6 | 0.16 | 0.15 | 0.17 | 0.16 | 0.16 | 0.16 | 0.160 | 4 |
| | 7 | 0.60 | 0.62 | 0.64 | 0.61 | 0.59 | 0.60 | 0.610 | 3 |
| | 8 | 2.35 | 2.28 | 2.48 | 2.40 | 2.30 | 2.30 | 2.352 | 3 |

*In. of water.

Table 22. (Continued)

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| A8 | 1 | | | | | | | | |
| | 2 | 0.004 | 0.006 | 0.006 | 0.005 | 0.005 | 0.004 | 0.0050 | 18 |
| | 3 | 0.012 | 0.014 | 0.012 | 0.014 | 0.013 | 0.013 | 0.0130 | 7 |
| | 4 | 0.039 | 0.044 | 0.042 | 0.045 | 0.042 | 0.045 | 0.0428 | 5 |
| | 5 | 0.120 | 0.120 | 0.120 | 0.120 | 0.120 | 0.120 | 0.1200 | 0 |
| | 6 | 0.44 | 0.41 | 0.44 | 0.44 | 0.44 | 0.44 | 0.435 | 3 |
| | 7 | 1.61 | 1.62 | 1.67 | 1.62 | 1.67 | 1.60 | 1.632 | 2 |
| | 8 | 6.05 | 6.35 | 6.05 | 5.85 | 6.35 | 6.05 | 6.117 | 3 |
| A9 | 1 | 0.002 | 0.002 | 0.004 | 0.002 | 0.002 | 0.002 | 0.0023 | 35 |
| | 2 | 0.010 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.0078 | 15 |
| | 3 | 0.016 | 0.016 | 0.016 | 0.018 | 0.019 | 0.017 | 0.0170 | 7 |
| | 4 | 0.063 | 0.067 | 0.065 | 0.064 | 0.072 | 0.065 | 0.0660 | 5 |
| | 5 | 0.20 | 0.22 | 0.20 | 0.21 | 0.21 | 0.21 | 0.208 | 4 |
| | 6 | 0.74 | 0.75 | 0.71 | 0.68 | 0.81 | 0.72 | 0.735 | 6 |
| | 7 | 2.85 | 2.81 | 2.62 | 2.92 | 3.05 | 2.75 | 2.833 | 5 |
| | 8 | 10.61 | 11.02 | 10.03 | 11.04 | 11.35 | 10.23 | 10.713 | 4 |
| A10 | 1 | 0.004 | 0.005 | 0.006 | 0.005 | 0.006 | 0.005 | 0.0052 | 15 |
| | 2 | 0.017 | 0.017 | 0.018 | 0.021 | 0.020 | 0.018 | 0.0185 | 28 |
| | 3 | 0.048 | 0.046 | 0.062 | 0.061 | 0.051 | 0.051 | 0.0532 | 13 |
| | 4 | 0.188 | 0.177 | 0.236 | 0.241 | 0.215 | 0.189 | 0.2076 | 13 |
| | 5 | 0.64 | 0.62 | 0.77 | 0.77 | 0.72 | 0.64 | 0.693 | 10 |
| | 6 | 2.38 | 2.26 | 2.99 | 2.82 | 2.62 | 2.36 | 2.572 | 11 |
| | 7 | 8.60 | 8.58 | 10.47 | 10.65 | 9.93 | 9.00 | 9.538 | 10 |
| | 8 | 22.79 | 22.45 | 27.65 | 28.65 | 25.78 | 23.70 | 25.170 | 10 |
| A11 | 1 | 0.010 | 0.011 | 0.012 | 0.014 | 0.010 | 0.010 | 0.0112 | 15 |
| | 2 | 0.037 | 0.040 | 0.044 | 0.053 | 0.036 | 0.034 | 0.0407 | 17 |
| | 3 | 0.108 | 0.115 | 0.127 | 0.157 | 0.106 | 0.097 | 0.1183 | 18 |
| | 4 | 0.43 | 0.46 | 0.49 | 0.63 | 0.43 | 0.38 | 0.470 | 19 |
| | 5 | 1.57 | 1.65 | 1.77 | 2.21 | 1.43 | 1.32 | 1.658 | 19 |
| | 6 | 5.31 | 5.87 | 5.91 | 7.55 | 4.91 | 4.70 | 5.708 | 18 |
| | 7 | 20.25 | 22.32 | 23.25 | 28.63 | 18.80 | 17.45 | 21.783 | 18 |
| | 8 | | | | | | | | |

Table 22. (Continued)

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| A12 | 1 | 0.016 | 0.018 | 0.020 | 0.022 | 0.019 | 0.016 | 0.0185 | 12 |
| | 2 | 0.075 | 0.063 | 0.085 | 0.079 | 0.076 | 0.082 | 0.0767 | 10 |
| | 3 | 0.218 | 0.193 | 0.243 | 0.239 | 0.206 | 0.187 | 0.2143 | 11 |
| | 4 | 0.88 | 0.87 | 0.95 | 0.98 | 0.84 | 0.75 | 0.878 | 9 |
| | 5 | 3.14 | 2.81 | 3.35 | 3.36 | 2.76 | 2.61 | 3.005 | 11 |
| | 6 | 10.41 | 10.04 | 11.44 | 11.86 | 9.55 | 9.30 | 10.433 | 10 |
| | 7 | 37.12 | 35.32 | 40.87 | 42.10 | 33.05 | 32.90 | 36.893 | 11 |
| | 8 | | | | | | | | |
| A13 | 1 | 0.032 | 0.057 | 0.046 | 0.062 | 0.041 | 0.048 | 0.0477 | 7 |
| | 2 | 0.175 | 0.258 | 0.208 | 0.313 | 0.190 | 0.220 | 0.2273 | 22 |
| | 3 | 0.541 | 0.820 | 0.616 | 0.924 | 0.556 | 0.647 | 0.6840 | 22 |
| | 4 | 2.12 | 3.15 | 2.50 | 3.67 | 2.37 | 2.63 | 2.740 | 21 |
| | 5 | 7.18 | 10.97 | 8.07 | 12.16 | 7.85 | 8.67 | 9.150 | 22 |
| | 6 | 27.31 | 41.37 | 32.31 | 44.73 | 30.61 | 32.13 | 34.743 | 20 |
| | 7 | | | | | | | | |
| | 8 | | | | | | | | |
| A14 | 1 | 0.083 | 0.084 | 0.071 | 0.092 | 0.083 | 0.082 | 0.0825 | 8 |
| | 2 | 0.406 | 0.474 | 0.369 | 0.498 | 0.410 | 0.391 | 0.4247 | 12 |
| | 3 | 1.265 | 1.428 | 1.087 | 1.491 | 1.236 | 1.176 | 1.2805 | 12 |
| | 4 | 5.06 | 5.49 | 4.41 | 5.86 | 5.06 | 4.61 | 5.082 | 9 |
| | 5 | 17.85 | 17.02 | 14.45 | 20.26 | 16.92 | 15.26 | 16.960 | 12 |
| | 6 | | | | | | | | |
| | 7 | | | | | | | | |
| | 8 | | | | | | | | |

Table 23. Calculated data for Test 5

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| A4 | 0.124 | 1 | | | |
| | | 2 | | | |
| | | 3 | | | |
| | | 4 | 0.1034 | 38 | 552 |
| | | 5 | 0.1934 | 70 | 377 |
| | | 6 | 0.3806 | 138 | 192 |
| | | 7 | 0.7798 | 284 | 127 |
| | | 8 | 1.5855 | 575 | 104 |
| A5 | 0.0800 | 1 | | | |
| | | 2 | | | |
| | | 3 | | | |
| | | 4 | 0.1034 | 58 | 927 |
| | | 5 | 0.1934 | 109 | 712 |
| | | 6 | 0.3806 | 215 | 505 |
| | | 7 | 0.7798 | 440 | 416 |
| | | 8 | 1.5855 | 895 | 356 |
| A6 | 0.0553 | 1 | | | |
| | | 2 | 0.0264 | 22 | 4,390 |
| | | 3 | 0.0484 | 40 | 2,320 |
| | | 4 | 0.1034 | 84 | 1,080 |
| | | 5 | 0.1934 | 158 | 1,140 |
| | | 6 | 0.3806 | 310 | 884 |
| | | 7 | 0.7798 | 636 | 709 |
| | | 8 | 1.5855 | 1,290 | 670 |
| A7 | 0.0313 | 1 | | | |
| | | 2 | 0.0264 | 58 | 7,770 |
| | | 3 | 0.0484 | 106 | 5,640 |
| | | 4 | 0.1034 | 226 | 3,200 |
| | | 5 | 0.1934 | 424 | 3,080 |
| | | 6 | 0.3806 | 834 | 2,600 |
| | | 7 | 0.7798 | 1,710 | 2,360 |
| | | 8 | 1.5855 | 3,470 | 2,200 |

Table 23. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| A8 | 0.0206 | 1 | | | |
| | | 2 | 0.0264 | 58 | 17,000 |
| | | 3 | 0.0484 | 106 | 13,100 |
| | | 4 | 0.1034 | 226 | 9,450 |
| | | 5 | 0.1934 | 424 | 7,550 |
| | | 6 | 0.3806 | 834 | 7,080 |
| | | 7 | 0.7798 | 1,710 | 6,330 |
| | | 8 | 1.5855 | 3,470 | 5,720 |
| A9 | 0.0142 | 1 | 0.0105 | 33 | 49,100 |
| | | 2 | 0.0264 | 84 | 26,400 |
| | | 3 | 0.0484 | 154 | 17,100 |
| | | 4 | 0.1034 | 328 | 14,600 |
| | | 5 | 0.1934 | 614 | 13,100 |
| | | 6 | 0.3806 | 1,210 | 12,000 |
| | | 7 | 0.7798 | 2,480 | 11,000 |
| | | 8 | 1.5855 | 5,040 | 10,000 |
| A10 | 0.00796 | 1 | 0.0105 | 59 | 111,000 |
| | | 2 | 0.0264 | 150 | 62,500 |
| | | 3 | 0.0484 | 274 | 53,600 |
| | | 4 | 0.1034 | 586 | 45,800 |
| | | 5 | 0.1934 | 1,100 | 43,600 |
| | | 6 | 0.3806 | 2,160 | 41,900 |
| | | 7 | 0.7798 | 4,420 | 37,000 |
| | | 8 | 1.5855 | 8,990 | 23,500 |
| A11 | 0.00495 | 1 | 0.0105 | 96 | 239,000 |
| | | 2 | 0.0264 | 241 | 138,000 |
| | | 3 | 0.0484 | 441 | 119,000 |
| | | 4 | 0.1034 | 942 | 104,000 |
| | | 5 | 0.1934 | 1,760 | 104,000 |
| | | 6 | 0.3806 | 2,470 | 93,000 |
| | | 7 | 0.7798 | 7,110 | 84,400 |
| | | 8 | | | |

Table 23. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| A12 | 0.00357 | 1 | 0.0105 | 132 | 395,000 |
| | | 2 | 0.0264 | 334 | 259,000 |
| | | 3 | 0.0484 | 612 | 216,000 |
| | | 4 | 0.1034 | 1,310 | 194,000 |
| | | 5 | 0.1934 | 2,440 | 189,000 |
| | | 6 | 0.3806 | 4,810 | 170,000 |
| | | 7 | 0.7798 | 9,860 | 143,000 |
| | | 8 | | | |
| A13 | 0.00206 | 1 | 0.0105 | 230 | 1,020,000 |
| | | 2 | 0.0264 | 578 | 768,000 |
| | | 3 | 0.0484 | 1,060 | 689,000 |
| | | 4 | 0.1034 | 2,260 | 605,000 |
| | | 5 | 0.1934 | 4,240 | 575,000 |
| | | 6 | 0.3806 | 8,340 | 566,000 |
| | | 7 | | | |
| | | 8 | | | |
| A14 | 0.00127 | 1 | 0.0105 | 372 | 1,760,000 |
| | | 2 | 0.0264 | 938 | 1,430,000 |
| | | 3 | 0.0484 | 1,720 | 1,290,000 |
| | | 4 | 0.1034 | 3,670 | 1,120,000 |
| | | 5 | 0.1934 | 6,870 | 1,070,000 |
| | | 6 | | | |
| | | 7 | | | |
| | | 8 | | | |

Table 24. Original and calculated data for Test 6

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| B3 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | 0.003 | 0.000 | 0.001 | 0.005 | 0.005 | 0.001 | 0.0025 | 87 |
| | 5 | 0.005 | 0.003 | 0.010 | 0.008 | 0.010 | 0.007 | 0.0072 | 84 |
| | 6 | 0.02 | 0.01 | 0.02 | 0.01 | 0.03 | 0.03 | 0.0200 | 45 |
| | 7 | 0.05 | 0.04 | 0.04 | 0.07 | 0.06 | 0.06 | 0.053 | 23 |
| | 8 | 0.12 | 0.15 | 0.13 | 0.06 | 0.13 | 0.20 | 0.132 | 35 |
| B4 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | 0.001 | 0.001 | 0.000 | 0.001 | 0.001 | 0.003 | 0.0011 | 82 |
| | 4 | 0.004 | 0.005 | 0.007 | 0.001 | 0.006 | 0.003 | 0.0043 | 78 |
| | 5 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.012 | 34 |
| | 6 | 0.02 | 0.03 | 0.03 | 0.02 | 0.06 | 0.04 | 0.033 | 46 |
| | 7 | 0.09 | 0.05 | 0.17 | 0.14 | 0.06 | 0.11 | 0.103 | 45 |
| | 8 | 0.27 | 0.37 | 0.37 | 0.37 | 0.45 | 0.30 | 0.355 | 18 |
| B5 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 | 0.0023 | 22 |
| | 4 | 0.008 | 0.009 | 0.005 | 0.007 | 0.007 | 0.008 | 0.0073 | 19 |
| | 5 | 0.02 | 0.02 | 0.03 | 0.01 | 0.02 | 0.02 | 0.020 | 32 |
| | 6 | 0.05 | 0.06 | 0.06 | 0.06 | 0.08 | 0.05 | 0.058 | 18 |
| | 7 | 0.20 | 0.16 | 0.18 | 0.20 | 0.18 | 0.15 | 0.178 | 12 |
| | 8 | 0.65 | 0.70 | 0.65 | 0.64 | 0.60 | 0.54 | 0.630 | 9 |
| B6 | 1 | | | | | | | | |
| | 2 | 0.002 | 0.002 | 0.002 | 0.003 | 0.002 | 0.002 | 0.0022 | 18 |
| | 3 | 0.003 | 0.005 | 0.006 | 0.006 | 0.005 | 0.004 | 0.0048 | 24 |
| | 4 | 0.018 | 0.015 | 0.019 | 0.018 | 0.018 | 0.015 | 0.0172 | 10 |
| | 5 | 0.045 | 0.060 | 0.040 | 0.050 | 0.050 | 0.050 | 0.0492 | 14 |
| | 6 | 0.16 | 0.18 | 0.19 | 0.17 | 0.20 | 0.17 | 0.1783 | 8 |
| | 7 | 0.62 | 0.65 | 0.66 | 0.69 | 0.73 | 0.61 | 0.660 | 7 |
| | 8 | 2.20 | 2.27 | 2.59 | 2.22 | 2.56 | 2.30 | 2.357 | 7 |

*In. of water.

Table 24. (Continued)

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| B7 | 1 | 0.003 | 0.002 | 0.001 | 0.003 | 0.001 | 0.002 | 0.0020 | 45 |
| | 2 | 0.005 | 0.006 | 0.005 | 0.005 | 0.006 | 0.006 | 0.0055 | 10 |
| | 3 | 0.011 | 0.013 | 0.011 | 0.013 | 0.011 | 0.012 | 0.0118 | 8 |
| | 4 | 0.036 | 0.041 | 0.043 | 0.038 | 0.040 | 0.038 | 0.0393 | 6 |
| | 5 | 0.13 | 0.14 | 0.13 | 0.12 | 0.12 | 0.13 | 0.128 | 6 |
| | 6 | 0.43 | 0.46 | 0.41 | 0.43 | 0.42 | 0.40 | 0.425 | 5 |
| | 7 | 1.53 | 1.76 | 1.37 | 1.49 | 1.54 | 1.46 | 1.525 | 8 |
| | 8 | 5.65 | 5.82 | 5.68 | 5.56 | 5.62 | 5.43 | 5.630 | 2 |
| B8 | 1 | 0.003 | 0.003 | 0.003 | 0.001 | 0.002 | 0.002 | 0.0023 | 34 |
| | 2 | 0.010 | 0.010 | 0.008 | 0.005 | 0.005 | 0.005 | 0.0072 | 35 |
| | 3 | 0.024 | 0.023 | 0.020 | 0.010 | 0.010 | 0.011 | 0.0163 | 41 |
| | 4 | 0.076 | 0.077 | 0.067 | 0.035 | 0.036 | 0.035 | 0.0543 | 44 |
| | 5 | 0.25 | 0.23 | 0.23 | 0.118 | 0.122 | 0.113 | 0.1772 | 37 |
| | 6 | 0.85 | 0.80 | 0.74 | 0.44 | 0.45 | 0.42 | 0.618 | 33 |
| | 7 | 3.09 | 2.66 | 2.82 | 1.75 | 1.74 | 1.64 | 2.283 | 28 |
| | 8 | 12.23 | 10.51 | 10.04 | 6.72 | 6.75 | 6.24 | 8.748 | 29 |
| B9 | 1 | 0.007 | 0.008 | 0.006 | 0.007 | 0.009 | 0.005 | 0.0068 | 20 |
| | 2 | 0.021 | 0.021 | 0.023 | 0.021 | 0.029 | 0.022 | 0.0228 | 14 |
| | 3 | 0.055 | 0.054 | 0.061 | 0.058 | 0.073 | 0.060 | 0.0601 | 11 |
| | 4 | 0.200 | 0.201 | 0.219 | 0.200 | 0.285 | 0.211 | 0.2193 | 15 |
| | 5 | 0.65 | 0.66 | 0.73 | 0.67 | 0.88 | 0.69 | 0.7133 | 12 |
| | 6 | 2.30 | 2.33 | 2.62 | 2.38 | 2.98 | 2.36 | 2.495 | 11 |
| | 7 | 8.94 | 8.87 | 10.00 | 8.84 | 10.40 | 9.06 | 9.352 | 7 |
| | 8 | | | | | | | | |
| B10 | 1 | 0.015 | 0.014 | 0.013 | 0.013 | 0.011 | 0.013 | 0.0132 | 10 |
| | 2 | 0.044 | 0.043 | 0.046 | 0.047 | 0.042 | 0.040 | 0.0437 | 6 |
| | 3 | 0.116 | 0.123 | 0.129 | 0.128 | 0.115 | 0.107 | 0.1197 | 7 |
| | 4 | 0.426 | 0.462 | 0.455 | 0.493 | 0.418 | 0.408 | 0.4437 | 7 |
| | 5 | 1.47 | 1.44 | 1.48 | 1.64 | 1.43 | 1.23 | 1.448 | 9 |
| | 6 | 4.95 | 4.94 | 5.22 | 5.53 | 4.66 | 4.27 | 4.928 | 9 |
| | 7 | 19.01 | 19.32 | 19.63 | 19.99 | 18.71 | 16.76 | 18.903 | 6 |
| | 8 | | | | | | | | |

Table 24. (Continued)

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* | Coefficient of variation % |
|---|---|---|---|---|---|---|---|---|---|
| B11 | 1 | 0.020 | 0.020 | 0.022 | 0.018 | 0.019 | 0.020 | 0.0198 | 7 |
| | 2 | 0.074 | 0.073 | 0.070 | 0.073 | 0.063 | 0.082 | 0.0725 | 8 |
| | 3 | 0.212 | 0.213 | 0.198 | 0.209 | 0.175 | 0.234 | 0.2068 | 9 |
| | 4 | 0.796 | 0.781 | 0.717 | 0.766 | 0.679 | 0.856 | 0.7658 | 8 |
| | 5 | 2.36 | 2.56 | 2.54 | 2.51 | 2.01 | 2.90 | 2.480 | 12 |
| | 6 | 8.42 | 8.76 | 8.58 | 8.98 | 7.70 | 10.29 | 8.789 | 10 |
| | 7 | 35.64 | 34.23 | 33.34 | 34.05 | 31.24 | 38.32 | 34.470 | 7 |
| | 8 | | | | | | | | |
| B12 | 1 | 0.069 | 0.050 | 0.037 | 0.062 | 0.050 | 0.046 | 0.0523 | 22 |
| | 2 | 0.323 | 0.202 | 0.157 | 0.280 | 0.236 | 0.221 | 0.2365 | 25 |
| | 3 | 1.027 | 0.591 | 0.472 | 0.876 | 0.691 | 0.640 | 0.7161 | 28 |
| | 4 | 4.11 | 2.46 | 1.82 | 3.60 | 2.80 | 2.66 | 2.908 | 28 |
| | 5 | 12.66 | 7.86 | 6.05 | 9.66 | 9.26 | 7.32 | 8.802 | 26 |
| | 6 | 43.99 | 29.04 | 20.91 | 34.50 | 31.70 | 24.46 | 30.766 | 26 |
| | 7 | | | | | | | | |
| | 8 | | | | | | | | |
| B13 | 1 | 0.065 | 0.078 | 0.061 | 0.058 | 0.055 | 0.092 | 0.0682 | 21 |
| | 2 | 0.322 | 0.368 | 0.296 | 0.271 | 0.249 | 0.432 | 0.3230 | 21 |
| | 3 | 0.976 | 1.106 | 0.866 | 0.770 | 0.730 | 1.270 | 0.9521 | 22 |
| | 4 | 3.91 | 4.31 | 3.58 | 3.20 | 2.95 | 5.15 | 3.850 | 21 |
| | 5 | 12.95 | 14.31 | 10.99 | 10.45 | 10.50 | 17.45 | 12.775 | 22 |
| | 6 | 56.00 | 51.48 | 43.46 | 38.46 | 37.16 | 53.60 | 46.693 | 17 |
| | 7 | | | | | | | | |
| | 8 | | | | | | | | |

Table 25. Calculated data for Test 6

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| B3 | 0.173 | 1 | | | |
| | | 2 | | | |
| | | 3 | | | |
| | | 4 | 0.1034 | 54 | 552 |
| | | 5 | 0.1934 | 102 | 453 |
| | | 6 | 0.3806 | 200 | 326 |
| | | 7 | 0.7798 | 410 | 205 |
| | | 8 | 1.5855 | 833 | 123 |
| B4 | 0.110 | 1 | | | |
| | | 2 | | | |
| | | 3 | 0.0484 | 40 | 1,110 |
| | | 4 | 0.1034 | 86 | 949 |
| | | 5 | 0.1934 | 160 | 755 |
| | | 6 | 0.3806 | 315 | 537 |
| | | 7 | 0.7798 | 645 | 399 |
| | | 8 | 1.5855 | 1,310 | 332 |
| B5 | 0.0828 | 1 | | | |
| | | 2 | | | |
| | | 3 | 0.0484 | 53 | 2,320 |
| | | 4 | 0.1034 | 114 | 1,610 |
| | | 5 | 0.1934 | 212 | 1,260 |
| | | 6 | 0.3806 | 418 | 945 |
| | | 7 | 0.7798 | 856 | 690 |
| | | 8 | 1.5855 | 1,740 | 589 |
| B6 | 0.0423 | 1 | | | |
| | | 2 | 0.0264 | 57 | 7,430 |
| | | 3 | 0.0484 | 104 | 4,830 |
| | | 4 | 0.1034 | 222 | 3,800 |
| | | 5 | 0.1934 | 416 | 3,090 |
| | | 6 | 0.3806 | 819 | 2,900 |
| | | 7 | 0.7798 | 1,680 | 2,560 |
| | | 8 | 1.5855 | 3,410 | 2,200 |

Table 25. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| B7 | 0.0269 | 1 | 0.0105 | 35 | 42,700 |
| | | 2 | 0.0264 | 89 | 18,600 |
| | | 3 | 0.0484 | 164 | 11,900 |
| | | 4 | 0.1034 | 350 | 8,680 |
| | | 5 | 0.1934 | 654 | 8,050 |
| | | 6 | 0.3806 | 1,290 | 6,920 |
| | | 7 | 0.7798 | 2,640 | 5,910 |
| | | 8 | 1.5855 | 5,360 | 5,260 |
| B8 | 0.0203 | 1 | 0.0105 | 47 | 49,100 |
| | | 2 | 0.0264 | 118 | 24,300 |
| | | 3 | 0.0484 | 217 | 16,400 |
| | | 4 | 0.1034 | 463 | 12,000 |
| | | 5 | 0.1934 | 866 | 11,100 |
| | | 6 | 0.3806 | 1,700 | 10,100 |
| | | 7 | 0.7798 | 3,490 | 8,850 |
| | | 8 | 1.5855 | 7,100 | 8,180 |
| B9 | 0.0104 | 1 | 0.0105 | 133 | 145,000 |
| | | 2 | 0.0264 | 336 | 77,000 |
| | | 3 | 0.0484 | 617 | 60,500 |
| | | 4 | 0.1034 | 1,320 | 48,400 |
| | | 5 | 0.1934 | 2,460 | 44,900 |
| | | 6 | 0.3806 | 4,848 | 40,600 |
| | | 7 | 0.7798 | 9,910 | 36,200 |
| | | 8 | | | |
| B10 | 0.00714 | 1 | 0.0105 | 187 | 282,000 |
| | | 2 | 0.0264 | 471 | 148,000 |
| | | 3 | 0.0484 | 863 | 120,000 |
| | | 4 | 0.1034 | 1,840 | 97,900 |
| | | 5 | 0.1934 | 3,450 | 91,100 |
| | | 6 | 0.3806 | 6,780 | 80,300 |
| | | 7 | 0.7798 | 13,900 | 73,300 |
| | | 8 | | | |

Table 25. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|
| B11 | 0.00510 | 1 | 0.0105 | 187 | 423,000 |
| | | 2 | 0.0264 | 471 | 245,000 |
| | | 3 | 0.0484 | 863 | 208,000 |
| | | 4 | 0.1034 | 1,840 | 169,000 |
| | | 5 | 0.1934 | 3,450 | 156,000 |
| | | 6 | 0.3806 | 6,780 | 143,000 |
| | | 7 | 0.7798 | 13,900 | 134,000 |
| | | 8 | | | |
| B12 | 0.00261 | 1 | 0.0105 | 365 | 1,120,000 |
| | | 2 | 0.0264 | 920 | 799,000 |
| | | 3 | 0.0484 | 1,690 | 721,000 |
| | | 4 | 0.1034 | 3,600 | 642,000 |
| | | 5 | 0.1934 | 6,740 | 554,000 |
| | | 6 | 0.3806 | 13,300 | 501,000 |
| | | 7 | | | |
| | | 8 | | | |
| B13 | 0.00192 | 1 | 0.0105 | 496 | 1,460,000 |
| | | 2 | 0.0264 | 1,250 | 1,090,000 |
| | | 3 | 0.0484 | 2,290 | 959,000 |
| | | 4 | 0.1034 | 4,810 | 850,000 |
| | | 5 | 0.1934 | 9,160 | 803,000 |
| | | 6 | 0.3806 | 18,000 | 760,000 |
| | | 7 | | | |
| | | 8 | | | |

Table 26. Original and calculated data for Test 7

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Static pressure drop* A | B | C | Mean pressure drop* | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| A5 | 0.080 | 1 | | | | | | | |
| | | 2 | | | | | | | |
| | | 3 | | | | | | | |
| | | 4 | | | | | | | |
| | | 5 | 0.1934 | 109 | 0.006 | 0.007 | 0.004 | 0.0057 | 358 |
| | | 6 | 0.3806 | 215 | 0.020 | 0.020 | 0.015 | 0.0183 | 298 |
| | | 7 | 0.7798 | 440 | 0.06 | 0.07 | 0.07 | 0.067 | 260 |
| | | 8 | 1.5855 | 895 | 0.27 | 0.26 | 0.22 | 0.250 | 234 |
| A7 | 0.0313 | 1 | | | | | | | |
| | | 2 | | | | | | | |
| | | 3 | 0.0484 | 70 | 0.003 | 0.002 | 0.003 | 0.0027 | 2,720 |
| | | 4 | 0.1034 | 149 | 0.011 | 0.010 | 0.010 | 0.0103 | 2,270 |
| | | 5 | 0.1934 | 279 | 0.032 | 0.030 | 0.029 | 0.0303 | 1,900 |
| | | 6 | 0.3806 | 549 | 0.115 | 0.11 | 0.11 | 0.112 | 1,820 |
| | | 7 | 0.7798 | 1,120 | 0.45 | 0.43 | 0.41 | 0.430 | 1,670 |
| | | 8 | 1.5855 | 2,280 | 1.74 | 1.77 | 1.67 | 1.727 | 1,610 |
| A9 | 0.0142 | 1 | | | | | | | |
| | | 2 | 0.0264 | 84 | 0.004 | 0.004 | 0.004 | 0.0043 | 14,600 |
| | | 3 | 0.0484 | 154 | 0.010 | 0.010 | 0.010 | 0.0100 | 10,100 |
| | | 4 | 0.1034 | 328 | 0.036 | 0.036 | 0.034 | 0.0353 | 7,790 |
| | | 5 | 0.1934 | 614 | 0.126 | 0.119 | 0.119 | 0.1213 | 7,630 |
| | | 6 | 0.3806 | 1,210 | 0.47 | 0.47 | 0.45 | 0.463 | 7,540 |
| | | 7 | 0.7798 | 2,480 | 1.99 | 1.91 | 1.87 | 1.923 | 7,450 |
| | | 8 | 1.5855 | 5,040 | 7.78 | 7.47 | 7.26 | 7.503 | 7,010 |

*In. of water.

Table 26. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Static pressure drop* A | B | C | Mean pressure drop* | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| A10 | 0.00796 | 1 | 0.0105 | 59 | 0.004 | 0.003 | 0.004 | 0.0037 | 79,000 |
| | | 2 | 0.0264 | 150 | 0.011 | 0.012 | 0.013 | 0.0120 | 40,500 |
| | | 3 | 0.0484 | 274 | 0.034 | 0.035 | 0.036 | 0.0350 | 35,200 |
| | | 4 | 0.1034 | 586 | 0.143 | 0.142 | 0.141 | 0.1420 | 31,300 |
| | | 5 | 0.1934 | 1,100 | 0.50 | 0.506 | 0.489 | 0.4983 | 31,300 |
| | | 6 | 0.3806 | 2,160 | 1.87 | 1.93 | 1.83 | 1.877 | 30,600 |
| | | 7 | 0.7798 | 4,420 | 7.18 | 7.14 | 7.24 | 7.187 | 27,800 |
| | | 8 | | | | | | | |
| A12 | 0.00357 | 1 | 0.0105 | 132 | 0.010 | 0.010 | 0.010 | 0.0100 | 214,000 |
| | | 2 | 0.0264 | 334 | 0.039 | 0.039 | 0.043 | 0.0403 | 136,000 |
| | | 3 | 0.0484 | 612 | 0.116 | 0.119 | 0.128 | 0.1210 | 122,000 |
| | | 4 | 0.1034 | 1,310 | 0.510 | 0.509 | 0.558 | 0.5257 | 116,000 |
| | | 5 | 0.1934 | 2,440 | 1.81 | 1.77 | 1.972 | 1.8507 | 116,000 |
| | | 6 | 0.3806 | 4,810 | 6.46 | 6.37 | 7.02 | 6.617 | 108,000 |
| | | 7 | 0.7798 | 9,860 | 24.61 | 23.85 | 26.35 | 24.937 | 96,600 |
| | | 8 | | | | | | | |

Table 27. Original and calculated data for Test 8

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Static pressure drop* A | B | C | Mean pressure drop* | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| A5 | 0.080 | 1 | | | | | | | |
| | | 2 | | | | | | | |
| | | 3 | | | | | | | |
| | | 4 | 0.1034 | 58 | 0.003 | 0.005 | 0.004 | 0.0040 | 883 |
| | | 5 | 0.1934 | 109 | 0.01 | 0.01 | 0.01 | 0.010 | 629 |
| | | 6 | 0.3806 | 215 | 0.02 | 0.01 | 0.03 | 0.020 | 326 |
| | | 7 | 0.7798 | 440 | 0.11 | 0.06 | 0.08 | 0.083 | 322 |
| | | 8 | 1.5855 | 894 | 0.35 | 0.28 | 0.34 | 0.323 | 302 |
| A7 | 0.0313 | 1 | | | | | | | |
| | | 2 | | | | | | | |
| | | 3 | 0.0484 | 70 | 0.005 | 0.003 | 0.004 | 0.0040 | 4,030 |
| | | 4 | 0.1034 | 149 | 0.016 | 0.017 | 0.019 | 0.0173 | 3,820 |
| | | 5 | 0.1934 | 279 | 0.05 | 0.05 | 0.05 | 0.050 | 3,140 |
| | | 6 | 0.3806 | 549 | 0.18 | 0.17 | 0.14 | 0.163 | 2,650 |
| | | 7 | 0.7798 | 1,120 | 0.68 | 0.67 | 0.62 | 0.657 | 2,550 |
| | | 8 | 1.5855 | 2,280 | 2.57 | 2.60 | 2.50 | 2.557 | 2,390 |
| A9 | 0.0142 | 1 | | | | | | | |
| | | 2 | 0.0264 | 84 | 0.008 | 0.009 | 0.006 | 0.0077 | 26,000 |
| | | 3 | 0.0484 | 154 | 0.019 | 0.019 | 0.017 | 0.0183 | 18,400 |
| | | 4 | 0.1034 | 328 | 0.066 | 0.074 | 0.066 | 0.0687 | 15,200 |
| | | 5 | 0.1934 | 614 | 0.214 | 0.223 | 0.216 | 0.2177 | 13,700 |
| | | 6 | 0.3806 | 1,210 | 0.76 | 0.79 | 0.78 | 0.777 | 12,600 |
| | | 7 | 0.7798 | 2,480 | 2.91 | 2.96 | 2.93 | 2.933 | 11,400 |
| | | 8 | 1.5855 | 5,040 | 11.03 | 11.27 | 11.05 | 11.117 | 10,400 |

*In. of water.

Table 27. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Static pressure drop* A | B | C | Mean pressure drop* | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| A10 | 0.00796 | 1 | 0.0105 | 59 | 0.004 | 0.004 | 0.006 | 0.0047 | 100,000 |
| | | 2 | 0.0264 | 150 | 0.020 | 0.020 | 0.022 | 0.0207 | 69,900 |
| | | 3 | 0.0484 | 274 | 0.054 | 0.054 | 0.059 | 0.0557 | 56,100 |
| | | 4 | 0.1034 | 586 | 0.211 | 0.214 | 0.235 | 0.2200 | 48,600 |
| | | 5 | 0.1934 | 1,100 | 0.69 | 0.70 | 0.76 | 0.717 | 45,100 |
| | | 6 | 0.3806 | 2,160 | 2.47 | 2.46 | 2.76 | 2.563 | 41,700 |
| | | 7 | 0.7798 | 4,420 | 9.31 | 9.34 | 10.46 | 9.703 | 37,600 |
| | | 8 | | | | | | | |
| A12 | 0.00357 | 1 | 0.0105 | 132 | 0.015 | 0.020 | 0.015 | 0.0167 | 357,000 |
| | | 2 | 0.0264 | 334 | 0.066 | 0.078 | 0.065 | 0.0697 | 235,000 |
| | | 3 | 0.0484 | 612 | 0.201 | 0.230 | 0.193 | 0.2080 | 209,000 |
| | | 4 | 0.1034 | 1,310 | 0.803 | 0.906 | 0.776 | 0.8283 | 183,000 |
| | | 5 | 0.1934 | 2,440 | 2.58 | 2.71 | 2.62 | 2.637 | 166,000 |
| | | 6 | 0.3806 | 4,810 | 8.67 | 9.48 | 8.94 | 9.030 | 147,000 |
| | | 7 | 0.7798 | 9,860 | 33.41 | 39.42 | 33.07 | 35.300 | 137,000 |
| | | 8 | | | | | | | |

Table 28. Original and calculated data for Test 9

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Static pressure drop* A | B | C | Mean pressure drop* | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| A5 | 0.080 | 1 | | | | | | | |
| | | 2 | | | | | | | |
| | | 3 | | | | | | | |
| | | 4 | 0.1034 | 58 | 0.002 | 0.002 | 0.001 | 0.0017 | 375 |
| | | 5 | 0.1934 | 109 | 0.006 | 0.006 | 0.005 | 0.0057 | 358 |
| | | 6 | 0.3806 | 215 | 0.01 | 0.01 | 0.02 | 0.013 | 212 |
| | | 7 | 0.7798 | 440 | 0.05 | 0.06 | 0.06 | 0.057 | 221 |
| | | 8 | 1.5855 | 894 | 0.23 | 0.22 | 0.25 | 0.233 | 218 |
| A7 | 0.0313 | 1 | | | | | | | |
| | | 2 | | | | | | | |
| | | 3 | 0.0484 | 70 | 0.003 | 0.002 | 0.003 | 0.0026 | 2,620 |
| | | 4 | 0.1034 | 149 | 0.010 | 0.008 | 0.008 | 0.0086 | 1,900 |
| | | 5 | 0.1934 | 279 | 0.029 | 0.024 | 0.027 | 0.0267 | 1,680 |
| | | 6 | 0.3806 | 549 | 0.10 | 0.08 | 0.10 | 0.093 | 1,510 |
| | | 7 | 0.7798 | 1,120 | 0.40 | 0.38 | 0.41 | 0.397 | 1,540 |
| | | 8 | 1.5855 | 2,280 | 1.62 | 1.52 | 1.67 | 0.160 | 1,500 |
| A9 | 0.0142 | 1 | | | | | | | |
| | | 2 | 0.0264 | 84 | 0.002 | 0.004 | 0.003 | 0.0030 | 10,100 |
| | | 3 | 0.0484 | 154 | 0.008 | 0.009 | 0.010 | 0.0090 | 9,090 |
| | | 4 | 0.1034 | 328 | 0.029 | 0.028 | 0.034 | 0.0030 | 6,620 |
| | | 5 | 0.1934 | 614 | 0.103 | 0.110 | 0.124 | 0.1123 | 7,060 |
| | | 6 | 0.3806 | 1,210 | 0.40 | 0.44 | 0.47 | 0.437 | 7,120 |
| | | 7 | 0.7798 | 2,480 | 1.69 | 1.86 | 2.03 | 1.860 | 7,200 |
| | | 8 | 1.5855 | 5,040 | 7.63 | 7.40 | 7.77 | 7.600 | 7,100 |

*In. of water.

Table 28. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Static pressure drop* A | B | C | Mean pressure drop* | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| A10 | 0.00796 | 1 | 0.0105 | 59 | 0.004 | 0.004 | 0.004 | 0.0040 | 85,500 |
| | | 2 | 0.0264 | 150 | 0.010 | 0.011 | 0.010 | 0.0103 | 34,800 |
| | | 3 | 0.0484 | 274 | 0.030 | 0.032 | 0.029 | 0.0303 | 30,500 |
| | | 4 | 0.1034 | 586 | 0.124 | 0.131 | 0.115 | 0.1233 | 27,200 |
| | | 5 | 0.1934 | 1,100 | 0.443 | 0.471 | 0.427 | 0.4470 | 28,100 |
| | | 6 | 0.3806 | 2,160 | 1.79 | 1.89 | 1.72 | 1.800 | 29,300 |
| | | 7 | 0.7798 | 4,420 | 6.90 | 7.19 | 6.62 | 6.903 | 26,800 |
| | | 8 | 1.5855 | 8,990 | 25.92 | 28.47 | 24.40 | 26.263 | 24,500 |
| A12 | 0.00357 | 1 | | | | | | | |
| | | 2 | 0.0264 | 334 | 0.029 | 0.040 | 0.034 | 0.0343 | 116,000 |
| | | 3 | 0.0484 | 612 | 0.088 | 0.123 | 0.100 | 0.1037 | 104,000 |
| | | 4 | 0.1034 | 1,310 | 0.388 | 0.551 | 0.441 | 0.4600 | 102,000 |
| | | 5 | 0.1934 | 2,440 | 1.433 | 1.838 | 1.672 | 1.6476 | 104,000 |
| | | 6 | 0.3806 | 4,810 | 5.23 | 6.66 | 5.99 | 5.960 | 97,000 |
| | | 7 | 0.7798 | 9,860 | 20.30 | 27.66 | 22.60 | 23.520 | 91,200 |
| | | 8 | | | | | | | |

Table 29. Original and calculated data for Test 10

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Static pressure drop* A | Static pressure drop* B | Static pressure drop* C | Mean pressure drop* | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| A5 | 0.080 | 1 | | | | | | | |
| | | 2 | | | | | | | |
| | | 3 | | | | | | | |
| | | 4 | 0.1034 | 58 | 0.002 | 0.002 | 0.003 | 0.0023 | 508 |
| | | 5 | 0.1934 | 109 | 0.01 | 0.01 | 0.01 | 0.0100 | 629 |
| | | 6 | 0.3806 | 215 | 0.03 | 0.03 | 0.02 | 0.0267 | 435 |
| | | 7 | 0.7798 | 440 | 0.07 | 0.09 | 0.08 | 0.0800 | 310 |
| | | 8 | 1.5855 | 899 | 0.27 | 0.29 | 0.31 | 0.2900 | 271 |
| A7 | 0.0313 | 1 | | | | | | | |
| | | 2 | | | | | | | |
| | | 3 | 0.0484 | 70 | 0.004 | 0.003 | 0.004 | 0.0037 | 3,730 |
| | | 4 | 0.1034 | 149 | 0.014 | 0.016 | 0.020 | 0.0167 | 3,690 |
| | | 5 | 0.1934 | 279 | 0.04 | 0.05 | 0.05 | 0.047 | 2,960 |
| | | 6 | 0.3806 | 549 | 0.15 | 0.16 | 0.16 | 0.157 | 2,560 |
| | | 7 | 0.7798 | 1,120 | 0.61 | 0.57 | 0.64 | 0.607 | 2,350 |
| | | 8 | 1.5855 | 2,280 | 2.40 | 2.30 | 2.44 | 2.380 | 2,240 |
| A9 | 0.0142 | 1 | | | | | | | |
| | | 2 | 0.0264 | 84 | 0.005 | 0.007 | 0.007 | 0.0063 | 24,300 |
| | | 3 | 0.0484 | 154 | 0.014 | 0.016 | 0.017 | 0.0157 | 15,800 |
| | | 4 | 0.1034 | 328 | 0.056 | 0.062 | 0.054 | 0.0573 | 12,600 |
| | | 5 | 0.1934 | 614 | 0.189 | 0.198 | 0.191 | 0.1927 | 12,100 |
| | | 6 | 0.3806 | 1,210 | 0.66 | 0.74 | 0.72 | 0.707 | 11,500 |
| | | 7 | 0.7798 | 2,480 | 2.15 | 2.81 | 2.67 | 2.543 | 9,860 |
| | | 8 | 1.5855 | 5,040 | 9.69 | 10.34 | 10.02 | 10.013 | 9,360 |

*In. of water.

Table 29. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Static pressure drop* A | B | C | Mean pressure drop* | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| A10 | 0.00796 | 1 | 0.0105 | 59 | 0.005 | 0.005 | 0.005 | 0.0050 | 107,000 |
| | | 2 | 0.0264 | 150 | 0.018 | 0.015 | 0.018 | 0.0170 | 57,400 |
| | | 3 | 0.0484 | 274 | 0.051 | 0.045 | 0.048 | 0.0480 | 48,300 |
| | | 4 | 0.1034 | 586 | 0.204 | 0.169 | 0.200 | 0.1910 | 42,200 |
| | | 5 | 0.1934 | 1,100 | 0.71 | 0.57 | 0.63 | 0.637 | 40,100 |
| | | 6 | 0.3806 | 2,160 | 2.55 | 2.07 | 2.26 | 2.229 | 36,300 |
| | | 7 | 0.7798 | 4,420 | 9.77 | 7.83 | 8.71 | 8.770 | 34,000 |
| | | 8 | | | | | | | |
| A12 | 0.00357 | 1 | | | | | | | |
| | | 2 | 0.0264 | 334 | 0.058 | 0.063 | 0.058 | 0.0597 | 202,000 |
| | | 3 | 0.0484 | 612 | 0.171 | 0.188 | 0.170 | 0.1763 | 178,000 |
| | | 4 | 0.1034 | 1,310 | 0.699 | 0.767 | 0.691 | 0.7190 | 159,000 |
| | | 5 | 0.1934 | 2,440 | 2.31 | 2.49 | 2.32 | 2.373 | 149,000 |
| | | 6 | 0.3806 | 4,810 | 8.04 | 8.83 | 8.06 | 8.310 | 135,000 |
| | | 7 | | | | | | | |
| | | 8 | | | | | | | |

Table 30. Original and calculated data for Test 11

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Static pressure drop* A | Static pressure drop* B | Static pressure drop* C | Mean pressure drop* | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| A5 | 0.080 | 1 | | | | | | | |
| | | 2 | | | | | | | |
| | | 3 | | | | | | | |
| | | 4 | | | | | | | |
| | | 5 | 0.1934 | 109 | 0.011 | 0.007 | 0.008 | 0.0087 | 547 |
| | | 6 | 0.3806 | 215 | 0.023 | 0.020 | 0.032 | 0.0025 | 407 |
| | | 7 | 0.7798 | 440 | 0.07 | 0.08 | 0.08 | 0.076 | 294 |
| | | 8 | 1.5855 | 894 | 0.24 | 0.25 | 0.32 | 0.270 | 252 |
| A7 | 0.0313 | 1 | | | | | | | |
| | | 2 | | | | | | | |
| | | 3 | 0.0484 | 70 | 0.003 | 0.004 | 0.002 | 0.0030 | 3,020 |
| | | 4 | 0.1034 | 149 | 0.013 | 0.009 | 0.011 | 0.0011 | 2,430 |
| | | 5 | 0.1934 | 279 | 0.035 | 0.040 | 0.040 | 0.0383 | 2,410 |
| | | 6 | 0.3806 | 549 | 0.13 | 0.14 | 0.13 | 0.133 | 2,170 |
| | | 7 | 0.7798 | 1,120 | 0.50 | 0.54 | 0.52 | 0.520 | 2,020 |
| | | 8 | 1.5855 | 2,280 | 2.01 | 2.03 | 1.99 | 2.010 | 1,880 |
| A9 | 0.0142 | 1 | | | | | | | |
| | | 2 | 0.0264 | 84 | 0.006 | 0.006 | 0.006 | 0.0060 | 20,300 |
| | | 3 | 0.0484 | 154 | 0.012 | 0.013 | 0.014 | 0.0130 | 13,100 |
| | | 4 | 0.1034 | 328 | 0.048 | 0.047 | 0.050 | 0.0483 | 10,700 |
| | | 5 | 0.1934 | 614 | 0.158 | 0.158 | 0.170 | 0.1600 | 10,100 |
| | | 6 | 0.3806 | 1,210 | 0.59 | 0.57 | 0.61 | 0.5900 | 9,610 |
| | | 7 | 0.7798 | 2,480 | 2.32 | 2.28 | 2.43 | 2.343 | 9,080 |
| | | 8 | 1.5855 | 5,040 | 8.65 | 8.45 | 9.42 | 8.840 | 8,260 |

*In. of water.

Table 30. (Continued)

| Sheet no. | F | Run no. | Apparent velocity ft/sec | Reynolds no. | Static pressure drop* A | B | C | Mean pressure drop* | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|---|---|---|
| A10 | 0.00796 | 1 | 0.0105 | 59 | 0.006 | 0.005 | 0.004 | 0.0050 | 107,000 |
| | | 2 | 0.0264 | 150 | 0.019 | 0.016 | 0.017 | 0.0173 | 58,400 |
| | | 3 | 0.0484 | 274 | 0.053 | 0.042 | 0.048 | 0.0477 | 48,000 |
| | | 4 | 0.1034 | 586 | 0.202 | 0.170 | 0.188 | 0.1867 | 41,200 |
| | | 5 | 0.1934 | 1,100 | 0.67 | 0.57 | 0.62 | 0.620 | 39,000 |
| | | 6 | 0.3806 | 2,160 | 2.42 | 2.07 | 2.31 | 2.267 | 36,900 |
| | | 7 | 0.7798 | 4,420 | 9.08 | 7.95 | 8.69 | 8.573 | 33,100 |
| | | 8 | | | | | | | |
| A12 | 0.00357 | 1 | 0.0105 | 132 | 0.010 | 0.011 | 0.011 | 0.0107 | 229,000 |
| | | 2 | 0.0264 | 334 | 0.051 | 0.049 | 0.044 | 0.0480 | 162,000 |
| | | 3 | 0.0484 | 612 | 0.149 | 0.152 | 0.143 | 0.1480 | 149,000 |
| | | 4 | 0.1034 | 1,310 | 0.618 | 0.611 | 0.586 | 0.6050 | 134,000 |
| | | 5 | 0.1934 | 2,440 | 1.92 | 2.04 | 1.95 | 1.970 | 124,000 |
| | | 6 | 0.3806 | 4,810 | 6.82 | 7.13 | 6.74 | 6.897 | 112,000 |
| | | 7 | 0.7798 | 9,860 | 25.56 | 26.91 | 25.49 | 25.987 | 101,000 |
| | | 8 | | | | | | | |

## APPENDIX B: DATA AND CALCULATIONS FOR CALIBRATING THE AIR DISPLACEMENT PUMP AND THIN PLATE ORIFICES

The apparatus used for supplying air consisted of an air displacement pump and an air turbine. The air flow rate from the displacement pump was determined by computing the rate of displacement of the 32-in.-diameter bell. The driving rack for the bell was measured to displace 18.85 in. for three revolutions of the pinion. The input speed to the first transmission was 238 $\pm$1 rpm. A second transmission, a fifty-to-one gear reducer and two chain drives were included in the power train. The gear ratios for the two transmissions are given in Table 31.

With the 32-in.-diameter bell, the three-speed transmission in first gear, the four-speed transmission in fourth gear, and sprocket ratios of 18:36 and 31:30, the air displacement rate was:

$$Q = \frac{(238)\ (31)\ (5.587)\ (6.283)\ (1)\ (252)\ (18)}{(30)\ (12)\ (50)\ (837)\ (36)} = 2.166 \text{ cfm}$$

The apparent velocity through the 8-in.-diameter column was:

$$2.166/0.349 = 6.206 \text{ ft/min}$$

Table 32 and 33 contain data to compare the air flow rates measured with the air displacement pump with those of the two smaller orifices. Table 34 is a comparison of the air flow rates measured with the larger orifice and those of a flow nozzle.

Table 31. Gear ratios for transmissions

| Gear | Three-speed transmission | Four-speed transmission |
|---|---|---|
| First | $\frac{252}{837}$ | $\frac{289}{1849}$ |
| Second | $\frac{350}{620}$ | $\frac{459}{1419}$ |
| Third | $\frac{1}{1} = 1$ | $\frac{612}{1032}$ |
| Fourth | --- | $\frac{1}{1} = 1$ |
| Reverse | $\frac{3780}{15903}$ | $\frac{5202}{40678}$ |

Table 32. Comparison of the observed flow rate through the 0.770-in.-diameter thin plate orifice with the air displacement pump

| Run no. | Orifice plate: Pressure drop | Orifice plate: Flow rate ($Q_1$) | Air displacement pump: Transmission gear 3-speed | Air displacement pump: Transmission gear 4-speed | Air displacement pump: Flow rate ($Q_2$) | Percent difference* |
|---|---|---|---|---|---|---|
| | in. of water | cfm | | | cfm | |
| 1 | 0.027 | 1.35 | R | R | 1.31 | 3.06 |
| 2 | 0.038 | 1.61 | R | 1 | 1.60 | 0.62 |
| 3 | 0.164 | 3.29 | R | 2 | 3.32 | 0.90 |
| 4 | 0.570 | 5.95 | R | 3 | 6.08 | 2.14 |
| 5 | 1.62 | 10.18 | R | 4 | 10.27 | 0.88 |
| 6 | 0.045 | 1.72 | 1 | R | 1.66 | 3.60 |
| 7 | 0.065 | 2.08 | 1 | 1 | 2.04 | 1.96 |
| 8 | 0.266 | 4.14 | 1 | 2 | 4.20 | 1.43 |
| 9 | 0.910 | 7.65 | 1 | 3 | 7.71 | 0.78 |
| 10 | 2.50 | 12.62 | 1 | 4 | 13.00 | 2.92 |
| 11 | 0.146 | 3.22 | 2 | R | 3.12 | 3.21 |
| 12 | 0.219 | 3.81 | 2 | 1 | 3.82 | 0.26 |
| 13 | 0.95 | 7.83 | 2 | 2 | 7.88 | 0.64 |
| 14 | 3.15 | 14.44 | 2 | 3 | 14.45 | 0.07 |
| 15 | 0.460 | 5.48 | 3 | R | 5.55 | 1.26 |
| 16 | 0.70 | 6.75 | 3 | 1 | 6.75 | 0.00 |
| 17 | 2.95 | 13.72 | 3 | 2 | 13.96 | 1.72 |

*Percent difference = $\left(\frac{Q_1-Q_2}{Q_2}\right)100$

Table 33. Comparison of the observed flow rate through the 0.9625-in.-diameter thin plate orifice with the air displacement pump

| Run no. | Orifice plate: Pressure drop (in. of water) | Orifice plate: Flow rate ($Q_1$) (cfm) | Air displacement pump: Transmission gear 3-speed | Air displacement pump: Transmission gear 4-speed | Air displacement pump: Flow rate ($Q_2$) (cfm) | Percent difference* |
|---|---|---|---|---|---|---|
| 1 | 0.010 | 1.30 | R | R | 1.31 | 0.76 |
| 2 | 0.016 | 1.64 | R | 1 | 1.60 | 2.50 |
| 3 | 0.068 | 3.32 | R | 2 | 3.32 | 0.00 |
| 4 | 0.226 | 6.01 | R | 3 | 6.08 | 1.15 |
| 5 | 0.643 | 10.10 | R | 4 | 10.27 | 1.66 |
| 6 | 0.016 | 1.64 | 1 | R | 1.66 | 1.20 |
| 7 | 0.025 | 2.03 | 1 | 1 | 2.04 | 0.49 |
| 8 | 0.107 | 4.16 | 1 | 2 | 4.20 | 0.95 |
| 9 | 0.360 | 7.54 | 1 | 3 | 7.71 | 2.20 |
| 10 | 1.055 | 13.10 | 1 | 4 | 13.00 | 0.77 |
| 11 | 0.057 | 3.04 | 2 | R | 3.12 | 2.56 |
| 12 | 0.087 | 3.76 | 2 | 1 | 3.82 | 1.57 |
| 13 | 0.378 | 7.78 | 2 | 2 | 7.88 | 1.27 |
| 14 | 1.30 | 14.30 | 2 | 3 | 14.45 | 1.04 |
| 15 | 3.55 | 23.50 | 2 | 4 | 24.37 | 3.58 |
| 16 | 0.185 | 5.45 | 3 | R | 5.52 | 1.27 |
| 17 | 0.278 | 6.68 | 3 | 1 | 6.75 | 1.04 |
| 18 | 1.22 | 13.87 | 3 | 2 | 13.96 | 0.64 |
| 19 | 3.90 | 24.70 | 3 | 3 | 25.60 | 3.52 |

*Percent difference = $\left(\frac{Q_1-Q_2}{Q_2}\right)100$

Table 34. Comparison of the observed flow rate through the 1.347-in.-diameter thin plate orifice with a 1.262-in.-diameter flow nozzle

| Run no. | Orifice plate | | Flow nozzle | | Percent difference* |
|---|---|---|---|---|---|
| | Pressure drop | Flow rate ($Q_1$) | Pressure drop | Flow rate ($Q_2$) | |
| | in. of water | cfm | in. of water | cfm | |
| 1 | 0.20 | 11.1 | 0.11 | 11.3 | 1.77 |
| 2 | 0.315 | 13.8 | 0.17 | 13.9 | 0.72 |
| 3 | 0.41 | 15.8 | 0.225 | 16.1 | 1.86 |
| 4 | 0.50 | 17.4 | 0.275 | 17.8 | 2.25 |
| 5 | 0.735 | 21.0 | 0.39 | 21.2 | 0.94 |
| 6 | 0.89 | 22.4 | 0.47 | 23.2 | 3.44 |
| 7 | 1.04 | 25.0 | 0.555 | 25.3 | 1.19 |
| 8 | 1.28 | 27.6 | 0.68 | 28.1 | 1.78 |
| 9 | 1.44 | 29.2 | 0.76 | 29.7 | 1.68 |
| 10 | 1.69 | 31.6 | 0.89 | 32.1 | 1.56 |
| 11 | 1.94 | 35.0 | 1.02 | 34.3 | 2.04 |
| 12 | 2.95 | 41.8 | 1.54 | 42.0 | 0.48 |
| 13 | 3.49 | 45.5 | 1.82 | 45.9 | 0.87 |
| 14 | 4.46 | 51.5 | 2.25 | 51.0 | 0.98 |
| 15 | 5.61 | 57.6 | 2.83 | 57.2 | 0.70 |
| 16 | 7.67 | 67.2 | 3.90 | 67.0 | 0.30 |
| 17 | 9.55 | 74.9 | 4.80 | 74.5 | 0.54 |
| 18 | 10.90 | 79.9 | 5.52 | 79.7 | 0.25 |

*Percent difference = $\left(\frac{Q_1-Q_2}{Q_2}\right)100$

## APPENDIX C: ORIGINAL AND CALCULATED DATA FOR AUXILIARY TESTS

In the process of conducting Tests 7 through 11, data were obtained with the system operating on both suction and pressure. The apparent static pressure drop across the perforated sheet was measured for both systems with the same filling of grain in the sheet metal column and at the same air flow rates. To pressurize the system for Runs 1 through 4, the direction of the air displacement pump was reversed from that for a suction system. For Runs 5 through 8, the turbine was turned so that its discharge was delivered into the duct work connecting with the plenum chamber.

Table 35. Comparison of the apparent static pressure drop through perforated sheets for a suction and pressure system. The perforated sheets were supporting corn

| Sheet no. | Run no. | $V_a$ ft/sec | $h_s$ in. of water | $h_p$ in. of water | $\frac{h_s-h_p}{h_s}$ |
|---|---|---|---|---|---|
| A7 | 1 | | | | |
| | 2 | | | | |
| | 3 | | | | |
| | 4 | 0.1034 | 0.010 | 0.008 | 0.20 |
| | 5 | 0.1934 | 0.030 | 0.028 | 0.07 |
| | 6 | 0.3806 | 0.11 | 0.09 | 0.18 |
| | 7 | 0.7798 | 0.43 | 0.33 | 0.23 |
| | 8 | 1.5855 | 1.77 | 1.30 | 0.27 |
| A10 | 1 | 0.0105 | 0.004 | 0.004 | 0.00 |
| | 2 | 0.0264 | 0.013 | 0.010 | 0.23 |
| | 3 | 0.0484 | 0.036 | 0.029 | 0.20 |
| | 4 | 0.1034 | 0.141 | 0.111 | 0.21 |
| | 5 | 0.1934 | 0.489 | 0.386 | 0.21 |
| | 6 | 0.3806 | 1.83 | 1.40 | 0.24 |
| | 7 | 0.7798 | 7.24 | 5.28 | 0.27 |
| | 8 | | | | |
| A12 | 1 | 0.0105 | 0.010 | 0.008 | 0.20 |
| | 2 | 0.0264 | 0.039 | 0.034 | 0.13 |
| | 3 | 0.0484 | 0.116 | 0.098 | 0.16 |
| | 4 | 0.1034 | 0.510 | 0.414 | 0.19 |
| | 5 | 0.1934 | 1.81 | 1.41 | 0.22 |
| | 6 | 0.3806 | 6.46 | 4.75 | 0.26 |
| | 7 | 0.7798 | 24.61 | 18.29 | 0.26 |
| | 8 | | | | |

Table 36. Comparison of the apparent static pressure drop through perforated sheets for a suction and pressure system. The perforated sheets were supporting wheat

| Sheet no. | Run no. | $V_a$ ft/sec | $h_s$ in. of water | $h_p$ in. of water | $\frac{h_s-h_p}{h_s}$ |
|---|---|---|---|---|---|
| A7 | 1 | | | | |
| | 2 | | | | |
| | 3 | 0.0484 | 0.005 | 0.005 | 0.00 |
| | 4 | 0.1034 | 0.016 | 0.012 | 0.25 |
| | 5 | 0.1934 | 0.050 | 0.040 | 0.20 |
| | 6 | 0.3806 | 0.180 | 0.140 | 0.22 |
| | 7 | 0.7798 | 0.68 | 0.48 | 0.29 |
| | 8 | 1.5855 | 2.57 | 2.00 | 0.22 |
| A10 | 1 | 0.0105 | 0.006 | 0.005 | 0.17 |
| | 2 | 0.0264 | 0.022 | 0.018 | 0.18 |
| | 3 | 0.0484 | 0.059 | 0.045 | 0.24 |
| | 4 | 0.1034 | 0.235 | 0.176 | 0.25 |
| | 5 | 0.1934 | 0.76 | 0.59 | 0.22 |
| | 6 | 0.3806 | 2.76 | 2.05 | 0.26 |
| | 7 | 0.7798 | 10.46 | 8.00 | 0.24 |
| | 8 | | | | |
| A12 | 1 | 0.0105 | 0.016 | 0.014 | 0.12 |
| | 2 | 0.0264 | 0.066 | 0.053 | 0.20 |
| | 3 | 0.0484 | 0.201 | 0.149 | 0.26 |
| | 4 | 0.1034 | 0.803 | 0.610 | 0.24 |
| | 5 | 0.1934 | 2.58 | 1.95 | 0.24 |
| | 6 | 0.3806 | 8.67 | 6.88 | 0.21 |
| | 7 | | | | |
| | 8 | | | | |

Table 37. Comparison of the apparent static pressure drop through perforated sheets for a suction and pressure system. The perforated sheets were supporting soybeans

| Sheet no. | Run no. | $V_a$ ft/sec | $h_s$ in. of water | $h_p$ in. of water | $\frac{h_s-h_p}{h_s}$ |
|---|---|---|---|---|---|
| A7 | 1 | | | | |
| | 2 | | | | |
| | 3 | | | | |
| | 4 | 0.1034 | 0.010 | 0.009 | 0.10 |
| | 5 | 0.1934 | 0.029 | 0.025 | 0.14 |
| | 6 | 0.3806 | 0.100 | 0.080 | 0.20 |
| | 7 | 0.7798 | 0.40 | 0.31 | 0.23 |
| | 8 | 1.5855 | 1.62 | 1.31 | 0.19 |
| A10 | 1 | 0.0105 | 0.004 | 0.002 | 0.50 |
| | 2 | 0.0264 | 0.010 | 0.008 | 0.20 |
| | 3 | 0.0484 | 0.030 | 0.024 | 0.20 |
| | 4 | 0.1034 | 0.124 | 0.105 | 0.15 |
| | 5 | 0.1934 | 0.443 | 0.356 | 0.20 |
| | 6 | 0.3806 | 1.79 | 1.33 | 0.26 |
| | 7 | 0.7798 | 6.90 | 5.03 | 0.27 |
| | 8 | 1.5855 | 25.92 | 20.10 | 0.22 |
| A12 | 1 | | | | |
| | 2 | 0.0264 | 0.029 | 0.025 | 0.14 |
| | 3 | 0.0484 | 0.088 | 0.077 | 0.13 |
| | 4 | 0.1034 | 0.388 | 0.334 | 0.14 |
| | 5 | 0.1934 | 1.433 | 1.124 | 0.22 |
| | 6 | 0.3806 | 5.23 | 3.98 | 0.24 |
| | 7 | 0.7798 | 20.30 | 15.22 | 0.25 |
| | 8 | | | | |

Table 38. Comparison of the apparent static pressure drop through perforated sheets for a suction and pressure system. The perforated sheets were supporting grain sorghum

| Sheet no. | Run no. | $V_a$ ft/sec | $h_s$ in. of water | $h_p$ in. of water | $\frac{h_s - h_p}{h_s}$ |
|---|---|---|---|---|---|
| A7 | 1 | | | | |
| | 2 | | | | |
| | 3 | 0.0484 | 0.004 | 0.003 | 0.25 |
| | 4 | 0.1034 | 0.020 | 0.016 | 0.20 |
| | 5 | 0.1934 | 0.050 | 0.040 | 0.20 |
| | 6 | 0.3806 | 0.160 | 0.130 | 0.19 |
| | 7 | 0.7798 | 0.64 | 0.47 | 0.27 |
| | 8 | 1.5855 | 2.44 | 1.85 | 0.24 |
| A10 | 1 | 0.0105 | 0.005 | 0.004 | 0.20 |
| | 2 | 0.0264 | 0.018 | 0.013 | 0.28 |
| | 3 | 0.0484 | 0.048 | 0.036 | 0.25 |
| | 4 | 0.1034 | 0.200 | 0.147 | 0.26 |
| | 5 | 0.1934 | 0.63 | 0.45 | 0.29 |
| | 6 | 0.3806 | 2.26 | 1.70 | 0.25 |
| | 7 | 0.7798 | 8.71 | 6.44 | 0.26 |
| | 8 | | | | |
| A12 | 1 | | | | |
| | 2 | 0.0264 | 0.058 | 0.044 | 0.24 |
| | 3 | 0.0484 | 0.171 | 0.131 | 0.23 |
| | 4 | 0.1034 | 0.699 | 0.523 | 0.25 |
| | 5 | 0.1934 | 2.31 | 1.75 | 0.24 |
| | 6 | 0.3806 | 8.04 | 5.91 | 0.27 |
| | 7 | | | | |
| | 8 | | | | |

Table 39. Comparison of the apparent static pressure drop through perforated sheets for a suction and pressure system. The perforated sheets were supporting rice

| Sheet no. | Run no. | $V_a$ ft/sec | $h_s$ in. of water | $h_p$ in. of water | $\frac{h_s-h_p}{h_s}$ |
|---|---|---|---|---|---|
| A7 | 1 | | | | |
| | 2 | | | | |
| | 3 | | | | |
| | 4 | 0.1034 | 0.011 | 0.009 | 0.18 |
| | 5 | 0.1934 | 0.040 | 0.030 | 0.25 |
| | 6 | 0.3806 | 0.130 | 0.100 | 0.23 |
| | 7 | 0.7798 | 0.52 | 0.38 | 0.27 |
| | 8 | 1.5855 | 1.99 | 1.36 | 0.32 |
| A10 | 1 | 0.0105 | 0.004 | 0.003 | 0.25 |
| | 2 | 0.0264 | 0.017 | 0.014 | 0.18 |
| | 3 | 0.0484 | 0.048 | 0.038 | 0.21 |
| | 4 | 0.1034 | 0.188 | 0.143 | 0.24 |
| | 5 | 0.1934 | 0.62 | 0.48 | 0.23 |
| | 6 | 0.3806 | 2.31 | 1.72 | 0.26 |
| | 7 | 0.7798 | 8.69 | 6.33 | 0.27 |
| | 8 | | | | |
| A12 | 1 | 0.0105 | 0.011 | 0.009 | 0.18 |
| | 2 | 0.0264 | 0.051 | 0.039 | 0.24 |
| | 3 | 0.0485 | 0.149 | 0.110 | 0.26 |
| | 4 | 0.1034 | 0.618 | 0.463 | 0.25 |
| | 5 | 0.1934 | 1.92 | 1.45 | 0.24 |
| | 6 | 0.3806 | 6.82 | 5.03 | 0.26 |
| | 7 | 0.7798 | 25.56 | 21.82 | 0.15 |
| | 8 | | | | |

Table 40. Original and calculated data for evaluating the influence of t/d ratio on the Euler number. (Corn supported on perforated sheets having 3/16-in.-diameter holes)

| Sheet no. | Run no. | Apparent static pressure drop* A | B | C | D | E | F | Mean pressure drop* |
|---|---|---|---|---|---|---|---|---|
| C1 | 1 | | | | | | | |
| | 2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0010 |
| | 3 | 0.002 | 0.002 | 0.004 | 0.002 | 0.002 | 0.002 | 0.0023 |
| | 4 | 0.005 | 0.009 | 0.009 | 0.008 | 0.007 | 0.009 | 0.0078 |
| | 5 | 0.026 | 0.026 | 0.030 | 0.021 | 0.019 | 0.026 | 0.0025 |
| | 6 | 0.08 | 0.06 | 0.11 | 0.09 | 0.08 | 0.09 | 0.085 |
| | 7 | 0.33 | 0.34 | 0.39 | 0.32 | 0.32 | 0.36 | 0.343 |
| | 8 | 1.30 | 1.26 | 1.45 | 1.22 | 1.21 | 1.40 | 1.307 |
| C2 | 1 | | | | | | | |
| | 2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0010 |
| | 3 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.003 | 0.0018 |
| | 4 | 0.008 | 0.005 | 0.007 | 0.007 | 0.006 | 0.006 | 0.0065 |
| | 5 | 0.021 | 0.022 | 0.021 | 0.028 | 0.022 | 0.019 | 0.0222 |
| | 6 | 0.07 | 0.07 | 0.06 | 0.09 | 0.07 | 0.08 | 0.073 |
| | 7 | 0.27 | 0.28 | 0.28 | 0.35 | 0.28 | 0.32 | 0.297 |
| | 8 | 1.06 | 1.06 | 1.07 | 1.22 | 1.06 | 1.21 | 1.111 |
| C3 | 1 | | | | | | | |
| | 2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0010 |
| | 3 | 0.003 | 0.003 | 0.002 | 0.003 | 0.003 | 0.003 | 0.0028 |
| | 4 | 0.007 | 0.007 | 0.007 | 0.007 | 0.009 | 0.009 | 0.0077 |
| | 5 | 0.022 | 0.020 | 0.021 | 0.021 | 0.025 | 0.024 | 0.0022 |
| | 6 | 0.07 | 0.08 | 0.08 | 0.08 | 0.08 | 0.09 | 0.0800 |
| | 7 | 0.27 | 0.29 | 0.28 | 0.28 | 0.32 | 0.33 | 0.295 |
| | 8 | 1.05 | 0.97 | 1.00 | 0.92 | 1.12 | 1.06 | 1.020 |

*In. of water.

Table 41. Calculated data for evaluating the influence of t/d ratio on the Euler number (Corn supported on perforated sheets having 3/16-in.-diameter holes)

| Sheet no. | F | Run no. | t/d | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|
| C1 | 0.0527 | 1 | 0.189 | | | |
| | | 2 | | 0.0264 | 33 | 3,380 |
| | | 3 | | 0.0484 | 84 | 2,320 |
| | | 4 | | 0.1034 | 178 | 1,720 |
| | | 5 | | 0.1934 | 333 | 1,570 |
| | | 6 | | 0.3806 | 656 | 1,380 |
| | | 7 | | 0.7798 | 1,340 | 1,330 |
| | | 8 | | 1.5855 | 2,800 | 1,220 |
| C2 | 0.0527 | 1 | 0.384 | | | |
| | | 2 | | 0.0264 | 33 | 3,380 |
| | | 3 | | 0.0484 | 84 | 1,810 |
| | | 4 | | 0.1034 | 178 | 1,430 |
| | | 5 | | 0.1934 | 333 | 1,400 |
| | | 6 | | 0.3806 | 656 | 1,190 |
| | | 7 | | 0.7798 | 1,340 | 1,150 |
| | | 8 | | 1.5855 | 2,800 | 1,040 |
| C3 | 0.0527 | 1 | 0.674 | | | |
| | | 2 | | 0.0264 | 33 | 3,380 |
| | | 3 | | 0.0484 | 84 | 2,820 |
| | | 4 | | 0.1034 | 178 | 1,700 |
| | | 5 | | 0.1934 | 333 | 1,380 |
| | | 6 | | 0.3806 | 656 | 1,300 |
| | | 7 | | 0.7798 | 1,340 | 1,140 |
| | | 8 | | 1.5855 | 2,800 | 950 |

Table 42. Original and calculated data for evaluating the influence of t/d ratio on Euler number (Wheat supported on perforated sheets having 3/16-in.-diameter holes)

| Sheet no. | Run no. | Apparent static pressure drop* | | | | | | Mean pressure drop* |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | |
| C1 | 1 | | | | | | | |
| | 2 | 0.001 | 0.001 | 0.001 | 0.002 | 0.001 | 0.002 | 0.0013 |
| | 3 | 0.003 | 0.004 | 0.003 | 0.004 | 0.003 | 0.004 | 0.0035 |
| | 4 | 0.010 | 0.016 | 0.011 | 0.010 | 0.012 | 0.011 | 0.0012 |
| | 5 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.040 |
| | 6 | 0.11 | 0.13 | 0.10 | 0.14 | 0.12 | 0.12 | 0.120 |
| | 7 | 0.41 | 0.53 | 0.54 | 0.49 | 0.42 | 0.34 | 0.455 |
| | 8 | 1.56 | 1.86 | 1.58 | 1.83 | 1.55 | 1.67 | 1.675 |
| C2 | 1 | | | | | | | |
| | 2 | 0.002 | 0.002 | 0.001 | 0.002 | 0.001 | 0.001 | 0.0015 |
| | 3 | 0.003 | 0.003 | 0.004 | 0.003 | 0.003 | 0.004 | 0.0033 |
| | 4 | 0.012 | 0.016 | 0.013 | 0.007 | 0.011 | 0.011 | 0.0117 |
| | 5 | 0.04 | 0.05 | 0.04 | 0.03 | 0.04 | 0.04 | 0.040 |
| | 6 | 0.13 | 0.14 | 0.12 | 0.11 | 0.11 | 0.11 | 0.120 |
| | 7 | 0.42 | 0.48 | 0.46 | 0.39 | 0.42 | 0.44 | 0.435 |
| | 8 | 1.63 | 1.85 | 1.73 | 1.38 | 1.49 | 1.63 | 1.618 |
| C3 | 1 | | | | | | | |
| | 2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0010 |
| | 3 | 0.003 | 0.003 | 0.003 | 0.005 | 0.004 | 0.004 | 0.0037 |
| | 4 | 0.014 | 0.010 | 0.010 | 0.008 | 0.013 | 0.014 | 0.0115 |
| | 5 | 0.04 | 0.04 | 0.04 | 0.03 | 0.03 | 0.04 | 0.037 |
| | 6 | 0.11 | 0.10 | 0.11 | 0.11 | 0.12 | 0.11 | 0.110 |
| | 7 | 0.37 | 0.35 | 0.40 | 0.43 | 0.42 | 0.37 | 0.390 |
| | 8 | 1.44 | 1.31 | 1.42 | 1.41 | 1.52 | 1.40 | 1.417 |

*In. of water.

Table 43. Calculated data for evaluating the influence of t/d on the Euler number (Wheat supported on perforated sheets having 3/16-in.-diameter holes)

| Sheet no. | F | Run no. | t/d | Apparent velocity ft/sec | Reynolds no. | $\frac{\Delta P}{\rho V_a^2}$ |
|---|---|---|---|---|---|---|
| C1 | 0.0527 | 1 | 0.189 | | | |
| | | 2 | | 0.0264 | 33 | 4,390 |
| | | 3 | | 0.0484 | 84 | 3,520 |
| | | 4 | | 0.1034 | 178 | 2,650 |
| | | 5 | | 0.1934 | 333 | 2,520 |
| | | 6 | | 0.3806 | 656 | 1,950 |
| | | 7 | | 0.7798 | 1,340 | 1,760 |
| | | 8 | | 1.5855 | 2,800 | 1,570 |
| C2 | 0.0527 | 1 | 0.384 | | | |
| | | 2 | | 0.0264 | 33 | 5,790 |
| | | 3 | | 0.0484 | 84 | 3,320 |
| | | 4 | | 0.1034 | 178 | 2,580 |
| | | 5 | | 0.1934 | 333 | 2,520 |
| | | 6 | | 0.3806 | 656 | 1,950 |
| | | 7 | | 0.7798 | 1,340 | 1,680 |
| | | 8 | | 1.5855 | 2,800 | 1,510 |
| C3 | 0.0527 | 1 | 0.674 | | | |
| | | 2 | | 0.0264 | 33 | 3,380 |
| | | 3 | | 0.0484 | 84 | 3,730 |
| | | 4 | | 0.1034 | 178 | 2,540 |
| | | 5 | | 0.1934 | 333 | 2,330 |
| | | 6 | | 0.3806 | 656 | 1,790 |
| | | 7 | | 0.7798 | 1,340 | 1,510 |
| | | 8 | | 1.5855 | 2,800 | 1,320 |

Table 44. Original data for the variations in apparent static pressure drop through a perforated sheet having a single 3/16-in.-diameter hole and supporting grain

| Grain | Run no. | System | Apparent static pressure drop (in. of water) A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|---|
| Corn | 1 | Suction | 1.114 | 0.469 | 0.448 | 1.741 | 0.227 | 0.400 |
| | 2 | " | 1.832 | 0.701 | 0.660 | 2.495 | 0.334 | 0.573 |
| Corn | 1 | Pressure | 1.086 | 0.404 | 0.360 | 0.896 | 0.190 | 0.293 |
| | 2 | " | 1.533 | 0.602 | 0.526 | 1.056 | 0.283 | 0.426 |
| Wheat | 1 | Suction | 1.118 | 2.687 | 1.348 | 2.402 | 1.266 | 1.166 |
| | 2 | " | 1.807 | 3.787 | 1.872 | 3.279 | 1.746 | 1.668 |
| Wheat | 1 | Pressure | 0.996 | 2.532 | 1.094 | 2.204 | 1.070 | 1.012 |
| | 2 | " | 1.434 | 3.658 | 1.538 | 3.087 | 1.558 | 1.408 |